TP-3851E

EVALUATION CRITERIA AND DETAILED PLANNING FOR A TWO-AXLE STEERABLE LOCOMOTIVE TRUCK

Prepared for the
Transportation
Development
Centre
by
Bombardier
Rail and Diesel
Products Division

OCTOBER 1982

CA1
DTC 801
8
E81
c.

Library and Information Centre / Centre de Documentation (GSLA)
RECEIVED - REÇU LE
APR 6 1983
Transport Canada / Transports Canada

EVALUATION CRITERIA AND DETAILED PLANNING FOR A TWO-AXLE STEERABLE LOCOMOTIVE TRUCK

Locomotive Research & Development Dept.
Bombardier Inc. Division des produits
ferroviaires et Diesel, Montreal
Report No. 438900-1
October 1982

THE CONTENTS OF THIS REPORT REFLECT THE
VIEWS OF THE CONTRACTOR AND NOT NECESSARILY
THE OFFICIAL VIEWS OR POLICIES OF THE TRANSPORTATION
DEVELOPMENT CENTRE

PROJECT TEAM

The project team was composed of:

For Bombardier Inc:

Mr. R. Bergner
Mr. D.D. Taylor
Mr. P.G. Whitby
Mr. D. Satsangi

For Dynamic Sciences Ltd.

Mr. P. Marcotte
Mr. R. Young
Mr. M. Kelley

For REA Ltd.

Mr. H. List

REPORT DOCUMENTATION FORM

1 Transport Canada Report No.	2 TDC Project No	3. Recipient's Catalogue No
TP 3851 E	#4717	

4 Title and Subtitle	5. Report Date
Evaluation Criteria and Detailed Planning for a two-axle steerable locomotive truck.	October 1982
	6. Performing Organization Report No: 438900-1
7. Author(s): P. G. Whitby	8 Transport Canada File No: D1465-290-3
9. Performing Organization Name and Address: Locomotive Research and Development Dept. Bombardier Inc. Railway & Diesel Products Div. 1505 Dickson, Montreal, Que. H1N 2H7	10. DSS File No.: N/A
	11. DSS or Transport Canada Contract No.: #4717
12 Sponsoring Agency Name and Address: Transportation Development Centre (TDC) 1000 Sherbrooke St. W. Montreal Que. H3A 2R3	13. Type of Report and Period Covered: Final April 1982-July 1982
	14. Sponsoring Agency Code
15. Supplementary Notes	16. TDC Project Officer: M. Audette

17 Abstract

Evaluation and planning activities conducted during the period April 1982 to July 1982 to develop a work plan and schedule for a study to determine the most feasible design for a 2-axle locomotive steerable truck are reported. Evaluation criteria and evaluation techniques were defined and a description was set forth for the reference truck and the two candidate truck designs that will be studied. Work statements were prepared and a specification network was established for successful completion of the project.

18 Key Words	19 Distribution Statement
Steerable Locomotive Trucks Steerable Axle Locomotive Trucks Locomotive Trucks, Radial Trucks Curving Resistance, Wheel Flange Wear	Limited number of copies available from TDC.

20 Security Classification (of this report)	21 Security Classification (of this page)	22. No. of Pages	23. Price
Nil	Nil	89	

TDC CDT 79-005

formule française au verso

FORMULE DE DOCUMENTATION POUR RAPPORT

1 Nº du rapport Transports Canada	2 Nº de l'étude — CDT	3 Nº de catalogue du destinataire
TP 3851 E	#4717	

4 Titre et sous-titre	5 Date du rapport
Evaluation criteria and detailed planning for a two-axle steerable locomotive truck.	Octobre 1982
	6 Nº du rapport de l'organisme exécutant 438900-1
7 Auteur(s) P. G. Whitby	8 Nº de dossier – Transports Canada D 1465-290-3
9 Nom et adresse de l'organisme exécutant Dépt. de recherche et développement des Locomotives. Bombardier Inc. Div. des produits ferroviaires et diesel 1505 rue Dickson, Montréal, Qué. H1N 2H7	10 Nº de dossier — ASC N/A
	11 Nº de contrat — ASC ou Transports Canada #4717
12 Nom et adresse de l'organisme parrain Transports Canada (CDT) Centre de développement des transports 1000 rue Sherbrooke, ouest Montréal, Qué. H3A 2R3	13 Genre de rapport et période visée Final avril 1982- juillet 1982
	14 Code de l'organisme parrain
15 Remarques additionnelles	16 Agent de projet — CDT M. Audette

17 Résumé

Un compte rendu de l'évaluation et de la planification des activités menées durant la période avril 1982 à juillet 1983 dans le but de développer une çédule et un plan de travail précisant le design (concept) le plus simple pour un chariot de direction à deux essieux, de locomotive. Les critères et techniques d'évaluation furent définis et une description fut exposée pour le chariot de repère ainsi que pour le design des deux chariots aspirants qui seront étudiés. Les exposés de travail furent préparés et une "Spécification" du réseau fut établie pour la réalisation du travail.

18 Mots-clés	19 Diffusion
Chariots de direction de locomotive Essieu de direction de locomotive Chariots de locomotive, chariots radiaux Résistance aux tournants Usure de flasque de roue.	Nombre de copies limité de CDT

20 Classification de sécurité (de ce rapport)	21 Classification de sécurité (de cette page)	22 Nombre de pages	23 Prix
Nil	Nil	89	

SUMMARY

This report covers work completed under Transport Canada service contract No. 4717 and constitutes the initial stages of a project to select a suitable design of two-axle steerable truck for use under North American freight locomotives.

RESULTS

Work done and described in this report consists of:

a) Planning the complete project
b) Defining the concepts to be analysed
c) Defining evaluation criteria
d) Defining analysis techniques
e) Producing a specification network with supporting documents covering the whole project.

CONCLUSIONS AND RECOMMENDATIONS

The definition and planning activities resulting from this project now make it possible to proceed with the planned selection of a two-axle steerable truck design.

It is recommended that a formal contract be authorized as soon as possible to avoid loss of countinuity and ensure the availability of qualified personnel to perform the work required to being the remaining truck selection activities to a successful conclusion.

CONTENTS

1. Description of Project — Page 1

2. Description of Candidate Designs — Page 2

3. Evaluation Criteria — Page 4

4. Techniques of Evaluation — Page 7

5. Work statements — Page 8

6. SPEC Documents — Page 8
   Appendix "A" D.S.L. Project C-220-1 Report
   Appendix "B" D.S.L. Project C-220-2 Report
   Appendix "C" Locomotive & Truck Designs
   Appendix "D" Work Statements
   Appendix "E" SPEC Documents

1.0 DESCRIPTION OF PROJECT

1.1 Object

The object of the project is to evaluate the possible improvements in locomotive traction, comfort and safety realizeable by the axles steering to reduce the angle of attack of the wheels to the rail, i.e. to become more closely radial to the center of curvature of the track.

TDC Service Contract No. 4717 covers the initial stages of this project and is the subject of this report.

1.2 Method

1.2.1. Bombardier Inc. are to use their computer capability to analyze and determine optimum suspension parameters to improve the dynamic behaviour of their standard zero weight transfer 2 axle truck.
This truck is known as the "Reference Truck" for this project.

1.2.2. Bombardier Inc. will design a new truck with axles located elastically in all directions. The suspension parameters will be optimized and all hardware items defined. This truck is called the "Flex truck".

1.2.3. Mr. List of R.E.A. Ltd. will supervise the design of a steerable-axle truck using his patented principles with inter axle linkage. Mr. List will use Bombardier drafting personnel and some engineering personnel on this project, but will use his own computer programs to analyze the dynamic behaviour of the truck, which is known as the "List Truck".

1.2.4. Details of the three candidate designs will be transmitted to D.S.L. who will build computer models of all three trucks to enable them to compare performance under a variety of simulated track conditions.

1.2.5. The cost to produce each design will be estimated and they will also be evaluated for ease of servicing, likely savings in track wear and suitability for freight locomotive service in North America.

1.2.6. Based on the information generated, a choice will be made for a steering-axle truck to be advanced to the prototype stage for testing. Costs to finalize designs, produce prototypes and test them will be estimated and included, with proposed test plans, in the final report of this project.

2.0 DESCRIPTION OF CANDIDATE DESIGNS

2.1 General

All three trucks will be of two axle design using the standard axle, 42" diameter wheels, G.E. traction motors and Timken journal bearings as on the standard Bombardier HR 412 locomotives. Single shoe brakes will be used on each wheel with composition shoes.
All designs will be for application to the Bombardier test locomotive. An arrangement of the locomotive is included in Appendix C of this report.

2.2 Reference Truck

This is basically the Bombardier Zero Weight Transfer truck for North American service. Changes to suspension units to optimize comfort and safety will be incorporated. An arrangement drawing of this truck is included in Appendix C of this report.

2.3 Flex Truck

A new design by Bombardier incorporates weight transfer control by the HI-AD method. Wheel base is very short and axles are located longitudinally and laterally by angled elastomeric suspension units and vertically by helicoidal springs.
A center pivot above the truck engages with horizontal traction pads mounted to the locomotive frame.
Secondary suspension is by four elastomeric spring units between the truck frame and the locomotive chassis. An arrangement sketch of this concept is included in Appendix C of this report.

2.4 List Truck

This truck allows inter-axle connection by means of two steering frames. The journal bearings and the motor nose suspension are both mounted on the frames which locates the wheel, axle, traction motor assembly. The two frames are joined at the center of the truck by a universal joint which allows angular and torsional movement between the frames. A vertical link from one frame to the bolster prevents both frames from pitching and absorbs any imbalance in torque reaction from the traction motors or brakes. Tractive forces from one axle are transmitted to the other steering frame by means of the universal joint and from that frame to two independent side frames by two low-level horizontal links. Primary suspension is by helical springs either side of the journal between the steering frames and the side frames. The secondary connection to the bolster is by a pair of inclined links at each side frame arranged so that their axes intersect at about track level to give zero weight transfer. The links act as swing hangers to allow lateral movement between the side frames and the bolster. The bolster has a

central pivot and transfer of vertical forces to the locomotive frame is through low friction pads which allow the truck to turn relative to the locomotive frame. The low friction pads are widely spaced in a fore and aft direction to give stability under traction.

3. EVALUATION CRITERIA

3.1. Evaluation of Performance Criteria

3.1.1. Appendix "A" is a report compiled by D.S.L. and titled "Evaluation Criteria/Steerable Truck" and dated May 1982. From page 16 onward is a list of criteria which it is proposed to evaluate by computer simulation.

3.1.2. The purpose behind the project is to evaluate the performance of the "Reference Truck", a non-steerable standard design with known characteristics, and to further evaluate improvements to be expected from the two other designs, i.e. The Bombardier "Flex Truck" and the "List Truck".

3.1.3. It is not proposed to specify minimum performance for the Traction, Comfort or Wear sections of the evaluation, but to produce data enabling a comparison to be made between the three designs.

3.1.4. In the case of Safety criteria a minimum performance, will be required based on F.R.A. track standards and considering a reduction in efficacity of hydraulic shock absorbers.

3.2 Simulated track conditions

Computer simulations for the following track conditions will be made.

3.2.1. Perfect Track

a) smooth, ideal tangent track;
b) smooth, ideal track with the following curvatures: 2.5°, 5°, 7.5°, 10°, 15°.

3.2.2. Simulated Real Track

D.S.L. will define and model the following 6 sections of test track.

a) average good track
b) average medium track
c) average bad track
d) rock & roll test track with successive large identical cross-level values at all staggered joints to excite body roll.
e) a single perturbation as severe as possible within the limits of F.R.A. class 2 track standards.
f) a single perturbation as severe as possible within the limits of F.R.A. class 4 track standards.

3.3. Traction Criteria

3.3.1. Steady State Weight Transfer on smooth, ideal tangent track (3.2.1.a) will be analyzed for traction and braking conditions.

3.3.2. Dynamic Weight Transfer on irregular tracks (3.2.2.a,b,c) will be analyzed for traction and braking conditions.

3.3.3. Steady State Traction Force/Wheel Creep characteristics will be analyzed on ideal, smooth tangent and curved track. (3.2.1a,b).

3.4. Safety Criteria

3.4.1. Ability to negotiate the following track sections with nominal damping rates reduced by 50% without producing L/V ratios greater than specified in par. 2.2. (iii) of appendix A is required,

a) Class 2 perturbation (3.2.2e) at 25 mph (40 kph) and class 4 perturbation (3.2.2.f) at 60 mph (97 kph) under the following conditions:

i) Full Traction (notch 8)
ii) Full Air Brake Emergency Application
iii) Full dynamic Braking.

b) The rock and roll track (3.2.2.d) at critical speed (determined by Simulation)

c) An 18° curve with drawbar pull of 350 K at elevation deficiency of 3 inches and surplus of 6 inches.

d) The most severe spiral that can be simulated with the limits of the F.R.A. track standards.

3.5. Comfort Criteria

3.5.1. Vertical and horizontal R.M.S. acceleration values will be calculated over the three real track sections (3.2.2.a,b,c.) at selected speeds based on anticipated resonances up to a reasonable maximum for each particular track.

Statistical graphs will be plotted showing the % of time exceeding specific acceleration values on each track section.

3.6. Track Wear Criteria

3.6.1. A wear index (Angle of Attack X Lateral Force) will be calculated at balance speed in the curved, smooth track sections(3.2.1.b)

3.6.2. RMS values of vertical and lateral forces at the wheel/rail interface will be calculated over the three real track sections (3.2.2.a,b,c).

Statistical graphs will be plotted showing % of time exceeding specific force levels for each track section.

Peak values of vertical and lateral/forces will be determined from the safety evaluation runs (3.4)

3.7. Truck Wear Criteria

3.7.1. Since wheel and truck forces are interactive, the same wear index (3.6.1) will be used for wheel wear evaluation.

3.7.2. R.M.S. values of vertical, lateral and longitudinal forces at the primary suspension (journal box) will be calculated over the three real track sections (3.2.2.a,b.c).

Statistical graphs will be plotted showing % of time exceeding specific force levels for each track section.

Total energy absorbed by dampers for each run will be calculated for each track section.

Peak values of vertical, lateral and longitudinal forces will be determined from the safety evaluation runs (3.4.)

4.0 EVALUATION TECHNIQUES

4.1 COMPUTER ANALYSIS

4.1.1. Appendix "B" is a report compiled by D.S.L. and titled "Proposed Analysis Methods - Steerable Truck Project" describing in broad terms the type of model they will use to analyse performance of the three candidate designs.

4.1.2. Values for steady state weight transfer under acceleration and braking will be generated for smooth, tangent track. Steady state traction force and wheel creep will be evaluated on smooth, perfect curved track.

4.1.3. Under dynamic conditions statistical graphs will be plotted of such parameters as accelerations and forces showing the % time in excess of particular values.

4.1.4. RMS values will be calculated for accelerations and forces under dynamic conditions.

4.1.5. Peak forces and accelerations will be recorded for the safety evaluation runs.

4.1.6. Total energy absorbed by dampers will be computed for the dynamic runs.

SERVICEABILITY

4.2.1. When the new concepts are finalized meetings will be held with Bombardier service personnel as well as with railroad personnel to attempt to define good and bad points from the maintenance point of view. Points felt to be unacceptable will be reviewed before continuing the project.

4.3 COST

4.3.1. When design details are complete, Bombardier staff will estimate the cost of a production run of each design.

4.3.2. It will be attempted to build a cost model for wheel and track wear. When wear index values are known for the different truck a probable lifetime saving will be computed.

5.0 WORK STATEMENTS

5.1. The Bombardier work statement is attached as Appendix D-1.

5.2. The D.S.L. work statement is attached as Appendix D-2.

5.3. The REA work statement is attached as Appendix D-3.

6.0 "SPEC" DOCUMENTS

6.1. A session was held at the C.P. Ltd Systems Services Planning Center on June 22nd and 23rd, 1982. The data to compile the following documents was generated:

a) A.F.D.A. Base
b) SPEC Network
c) R.A.C. Matrix
d) Velocity diagram for the first 12 weeks of Phase II of the project.
e) A calendar correlating project week numbers with actual dates.

A set of these documents is included as Appendix "E".

APPENDIX A

TO

REPORT 438900-1

EVALUATION CRITERIA

STEERABLE TRUCK

BY

DSL DYNAMIC SCIENCES LTD.

Project C 220-1

EVALUATION CRITERIA

STEERABLE TRUCK PROJECT

by

DSL DYNAMIC SCIENCES LIMITED

for

BOMBARDIER LTD.
RAIL AND DIESEL PRODUCT DIVISION

Project C220-1,
May, 1982

1. SCOPE OF THE REPORT

This report discusses Evaluation Criteria to be used in comparing the candidate locomotive trucks. It covers performance aspects such as traction and operational safety which are affected by vehicle dynamics aspects.

2. LITERATURE REVIEW

2.1 INTRODUCTION

Considering that the inclusion of steering into a locomotive truck is a fundamental change with respect to traditional designs using pedestal guides, it is important to provide at the analysis stage a thorough examination of all operational factors affecting its performance. This will ensure that no aspects are neglected and that a proper perspective will be obtained concerning the various performance aspects of the candidate designs. For the above reasons, it was found necessary to review a selection of standards and recommended practice manuals in order to extract relevant material useful in the definition of evaluation criteria. The first section below presents the results of this investigation.

Considering that the proposed new locomotive must later be demonstrated in actual railway service, it is desirable to use evaluation methods that are compatible with existing railway testing procedures. In this respect, a selection of technical publications have been used to demonstrate test procedures used to evaluate locomotive performance. Results of this investigation are presented in the next section.

In the last section, a list is included outlining the proposed evaluation criteria for the project.

2.2 REVIEW OF SELECTED "STANDARDS"

The following is a presentation of selected documents which have received official recognition, and for the purpose of this report have been classified as Standards.

Only aspects relevant to locomotive performance evaluation have been retained.

i) METHODS OF DETERMINING ALLOWABLE TRAIN SPEED - Ministry of Railway Transport of the USSR, Moscow 1972 (English Translation).

This document outlines procedures to be followed in the determination of maximum speed of railway vehicles, including requirements for analytical as well as test work. An example case of test results is also given for an electric type 6-axle locomotive.

REQUIREMENTS FOR CALCULATION PRIOR TO TESTS

- Dynamic Curving forces up to 6" cant deficiency
- Vehicle Natural frequencies, damping factors and resonnant speeds.

TEST REQUIREMENTS

- Drop tests using wedges on the rail for verification of natural frequency calculations.
- Curving tests at 4 discrete values of track curvature (approx. 1.5, 3, 6, 12 deg. of curvature).
- High speed runs on tangent track on the lightest railway bed that the equipment will operate.

- Test over artificial track geometry defects, corresponding to maximum allowable track defect characteristics.

Note: For locomotives, there is a requirement for organizing the test consist in push-pull configuration in order to allow testing in both directions at the desired speeds and to account for any asymmetric properties of the running gear.

MEASURES OF PERFORMANCE

The following variables must be measured under test, both on tangent and curved track.

- Stresses in the rail base edges
- Vertical and lateral tie-plate loads
- Railhead lateral deflections and dynamic rail roll angles
- Wheel-rail lateral and vertical forces
- Acceleration levels on the locomotive body
- Soil and ballast stresses

ACCEPTABILITY CRITERIA

- Rail base edge stresses not to exceed allowable stresses for the specific rail material
- Vertical wheel load not to exceed allowable fatigue stresses for the specific wheels and rail materials
- Soil and ballast stresses not to exceed allowable values for the specific grades of material
- Lateral Frame Force on wheelset not to exceed 0.3 times the static axle load
- Lateral to vertical tie-plate load not to exceed a ratio of 1.1 to 1.4 depending on the type of ballast used
- Ride to be better than a specified Sperling Ride Index value (for locomotives the specified index is 3.25).

ii) "GUIDE FOR THE EVALUATION OF HUMAN EXPOSURE TO WHOLE BODY VIBRATION"

International Standard ISO 2631 (1978)

SCOPE

Establishing limits of exposure to vibrations transmitted from solid surfaces to the human body in frequency range 1 to 80 Hz.

MEASURES OF PERFORMANCE

Accelerations in the vertical and lateral directions.

ACCEPTABILITY CRITERIA

The case of a locomotive would normally fall under the category "Decreased Proficiency Boundary". Relevant extracts from the standard are included in Appendix A.

iii) AAR STANDARD M-965-76

AAR Manual of Standards and Recommended Practices

This specification is intended for freight cars and not for locomotives. However, it is the only official Performance Test Requirement in North America that we know of concerning the safe negotiation of track geometry defects.

SCOPE

To establish the acceptability of trucks or special devices (e.g. dampers) to control the roll oscillations of freight cars over staggered rail joints. Applicable to car having truck center distances of 36 to 42 ft. and center of gravity height of 84 inches or more.

(Note: These characteristics are not significantly higher than those existing on typical North American locomotives).

TEST PROCEDURE

The vehicle is run at increasing speeds on a 9 degree curve having 6" of superelevation. The track is especially set up with 20 staggered vertical geometry irregularities having ¾" amplitude which simulate poor rail joints.

MEASURES OF PERFORMANCE AND ACCEPTABILITY CRITERIA

- Total roll angle not to exceed 6 degrees.
- Lateral acceleration at the C. of G. not to exceed 0.35g.
- Wheel lift limited to ½ inch.

iv) FEDERAL TRACK SAFETY STANDARDS

PART 213 TRACK SAFETY STANDARDS

Federal Railroad Safety Act of 1970.

SCOPE

This standard defines amongst other aspects, standards of acceptability for the physical conditions of the track at given speeds (i.e. classification system 1 to 6).

Although the standard does not relate directly to the performance evaluation of locomotives, it is relevant in the sense that the specifications for allowable track geometry defects may be used to set up simulated test conditions.

MEASURES OF PERFORMANCE TRACK GEOMETRY

- Track gauge
- Vertical irregularities (mid-chord offset in 62 ft.)
- Lateral (alignment) irregularities (mid-chord offset in 62 ft.)
- Cross level irregularities
- Elevation on curves
- Rail end batter

ACCEPTABILITY CRITERIA

Various sets of acceptable maximum levels (i.e. of the measures of performance listed above) are specified according to the operating speeds. Details can be obtained in the standard itself.

v) MISCELLANEOUS

Various design rules have also been developed by tradition which outline specific requirements for railway vahicles. They may sometimes only be used as informal rules at the design stage or may be included in specifications for equipment.

A sample list is included below. It has been extracted from a Specification for a Passenger Locomotive.

SELECTED SPECIFICATION ITEMS

- Minimum limits on primary suspension static deflection
- Minimum limit on suspension travel
- Limits on truck pitch natural frequencies (upper and lower limits) and maximum gain at resonance
- Maximum limits on unsprung weight
- Requirements on damper types and characteristics
- Limits on various wheel and axle Lateral to Vertical Force Ratios (i.e. single wheel L/V ratio, axle L/V ratio and "truckside" L/V ratio).

2.2 REVIEW OF TEST PROCEDURE

This section examines a selection of technical publications where test procedures are described relating to locomotive performance evaluation.

i) DESIGN FEATURES AND PERFORMANCE CHARACTERISTICS OF THE HIGH TRACTION, THREE-AXLE TRUCK

H.A. Marta, K.D. Mels, G.S. Itami. ASME Publication.

This reference describes the evaluation of weight transfer characteristics.

The evaluation of weight transfer characteristics under tractive effort is a standard method of assessing locomotive performance. This evaluation is generally carried out by calculations based on a simplified representation of the suspension system. The measure of performance is called adhesion efficiency, defined as the ratio of minimum axle load for a specific tractive effort to the nominal static axle load.

In the reference, weight transfer characteristics were actually measured by test using electronic scales. Experimental results were found to differ from theoretical results by an amount representing 30% of the predicted weight transfer magnitude. In the reference, this error is considered small in terms of overall traction performance, and therefore no validated data is given explaining the differences between experimental and theoretical results.

ii) SUPER SERIES WHEEL CREEP CONTROL SYSTEM

B.R. Meyer, A.P. de Buhr. ASME Paper 1980 - WA/RT-3

This reference examines the performance of a specific wheel slip control system used on a locomotive.

MEASURES OF PERFORMANCE

Two methods are used to evaluate the system performance.

- Maximum traction force of each wheelset
- Friction-creep characteristics of each wheelset (i.e. a plot of traction force versus percentage wheel slip).

EXPERIMENTAL PROCEDURES

Locomotives are run under a variety of operational conditions including contaminants on the rail, sand, running speed and track characteristics such as curvature. Maximum traction force is evaluated at each axle from motor current measurements.

Friction creep characteristics are evaluated by special test procedures where the motor current is recorded as the creepage is increased. This allows to determine the maximum available friction as well as the creepage value at which the maximum friction is obtained. It should be noted that the calculation of adhesion is based on calculated weight transfer characteristics (as described previously) as opposed to measured ones.

(iii) WHEEL AND RAIL LOADINGS FROM DIESEL LOCOMOTIVES, by L.F. Koci. Association of American Railroads Conference on Track/Train Dynamics Interaction. Dec. 15, 1971.

This paper discusses locomotive curve negotiation dynamics, in the context of 10 unexplained derailment case studies on various U.S. Railroads.

Operational safety is evaluated from wheel rail vertical forces obtained from dynamometer wheelsets. Performance acceptability criteria are stated as follows.

1. Wheel Climbing the Rail: Lateral-to-vertical wheel load ratio (L/V) equal to, or less than 0.9 at the leading outer wheel
2. Rail Rollover: L/V for one side of an entire truck $\left(=\frac{L_1 + L_2 + L_3}{V_1 + V_2 + V_3}\right)$ equal to or less than 0.5
3. Track Shifting: Net lateral axle load equal to or less than 40% of the vertical axle load.

Time duration aspects of the various L/V ratios for which these criteria apply are not discussed, however it is stated that based on their field experience with instrumented wheelsets, most dynamic peak forces are of short duration, typically less than 0.1 second. It is also stated that such short duration forces are not believed to be significant from an Operational Safety point of view.

Concerning the nature of typical track irregularities, statistical data are given on typical North American track, in the form of relative frequency of occurrence for various levels of peak-to-peak track vertical irregularities. Such data is given for track sections typical of four railroads, showing a range of expectable quality of track geometry.

(iv) A DESCRIPTION OF THE TESTS CONDUCTED AND DATA OBTAINED DURING THE PERTURBED TRACK TEST

M. Coltman, R. Brantman, P. Tong. FRA/ORD-80/15.

SCOPE

The report describes the Perturbed Track Test and Pilot Test conducted at the Transportation Test Center in Pueblo, Colorado, in 1978 and 1979. The tests involved two typical AMTRAK six-axle locomotives and two typical four-axle freight locomotives.

An important objective of the test was to evaluate the capability of controlled perturbed track testing for the determination of locomotive operational safety.

TEST PROCEDURE

Various locomotive types were run under several test conditions. Variable test conditions included the following:

- Track Curvature
- Operating Speed
- Track Perturbations (i.e. especially prepared track geometry irregularities of known characteristics of wavelength and amplitude: See Appendix B for more details)
- Miscellaneous locomotive control settings such as Traction Dynamic Brakes and Sanding
- Miscellaneous suspension configurations (e.g. damping, wheel size differential)

MEASURES OF PERFORMANCE

- Wheel-rail lateral and vertical forces on the leading axle of the trailing truck.
- Linear and angular accelerations about the three principal axes of the locomotive.

ACCEPTABILITY CRITERIA

No criteria of acceptability are given with respect to operational safety, and no derailments occurred during the tests.

3. PROPOSED EVALUATION CRITERIA

The section below describes the proposed evaluation criteria. Judging from the discussions in the previous sections, it is unusual to attempt to cover all aspects of performance simultaneously. Because there is generally some overlapping between the various performance aspects (e.g. a truck pitch resonance problem would affect simultaneously traction, ride safety and truck maintenance), it is found useful to classify the aspects of performance as indicated below. The classification system will provide a full coverage of all performance aspects, in a manner which can be updated and perfected as conditions require.

CLASSIFICATION TABLE

1. OPERATIONAL CAPABILITIES
   - 1.1 Traction
   - 1.2 Operational Safety
   - 1.3 Comfort

2. COMPONENT LIFE CYCLES EVALUATION
   - 2.1 Track Components
   - 2.2 Locomotive Components

In order to provide quantitative evaluation of each performance aspect, specific items are identified having measurable characteristics. These are the evaluation criteria as listed below. They were selected based on the techniques previously described in section 2 (i.e. Standards and Test Procedures).

In the list below, only functional descriptions of the evaluation criteria are given. The detailed specification of the levels of acceptability (e.g. limits on L/V ratios, or rail wear parameters), as well as the detailed specification for the operational conditions under which the performance will be evaluated (e.g. the magnitude of the track geometry defects, the rail adhesion, the application of traction or brakes, etc), are covered under a separate document, and the responsibility of Bombardier (with DSL assistance as required).

LIST OF EVALUATION CRITERIA

1. OPERATIONAL CAPABILITIES

1.1 TRACTION

- Steady-state Weight Transfer characteristics under tractive effort, considering smooth ideal tangent track.
- Dynamic Weight Transfer characteristics under tractive effort, considering effects of locomotive dynamics subjected to realistic levels of track irregularities.
- Steady-state Traction Force/Wheel Creep characteristics on ideal smooth tangent and curved track.
- Steady-state Weight Transfer characteristics under braking, considering smooth ideal tangent track.
- Dynamic Weight Transfer characteristics under braking, considering effects of locomotive dynamics under realistic levels of track irregularities.

1.2 OPERATIONAL SAFETY

- Ability to negotiate safely and without track damage maximum allowable values of track geometry defects in each respective speed range. The performance analysis will consider a variety of operational conditions including throttle and brake settings, overspeeds on tangent and curved track as well as possible suspension component failures or inadequate maintenance.
- Ability to negotiate safely and without track damage, allowable limits of track curvature, under unfavorable conditions of coupler angles and coupler forces.
- Ability to negotiate safely and without track damage, high magnitudes of track twist conditions such as those found on superelevated curve entry and exit spirals.

1.3 COMFORT

. Ability to provide good ride qualities in the cab, under realistic track geometry conditions, on tangent track and on curves.

2. COMPONENT LIFE CYCLES EVALUATION

2.1 TRACK COMPONENTS

- Ability to minimize curving forces and rail wear parameters on ideal smooth curved track.
- Ability to minimize dynamic forces on the track structure under realistic levels of track geometry quality, but not considering mechanical shocks such as those resulting from flat spots or transients at welded rail joints.

2.2 LOCOMOTIVE COMPONENTS

- Ability to minimize wheel flange wear parameters on ideal smooth curved track.
- Ability to minimize dynamic vertical and lateral forces at the primary suspension, under realistic levels of track geometry quality.

APPENDIX A

Extracts from ISO standard 2631 / Fatigue-Decreased Proficiency Boundaries

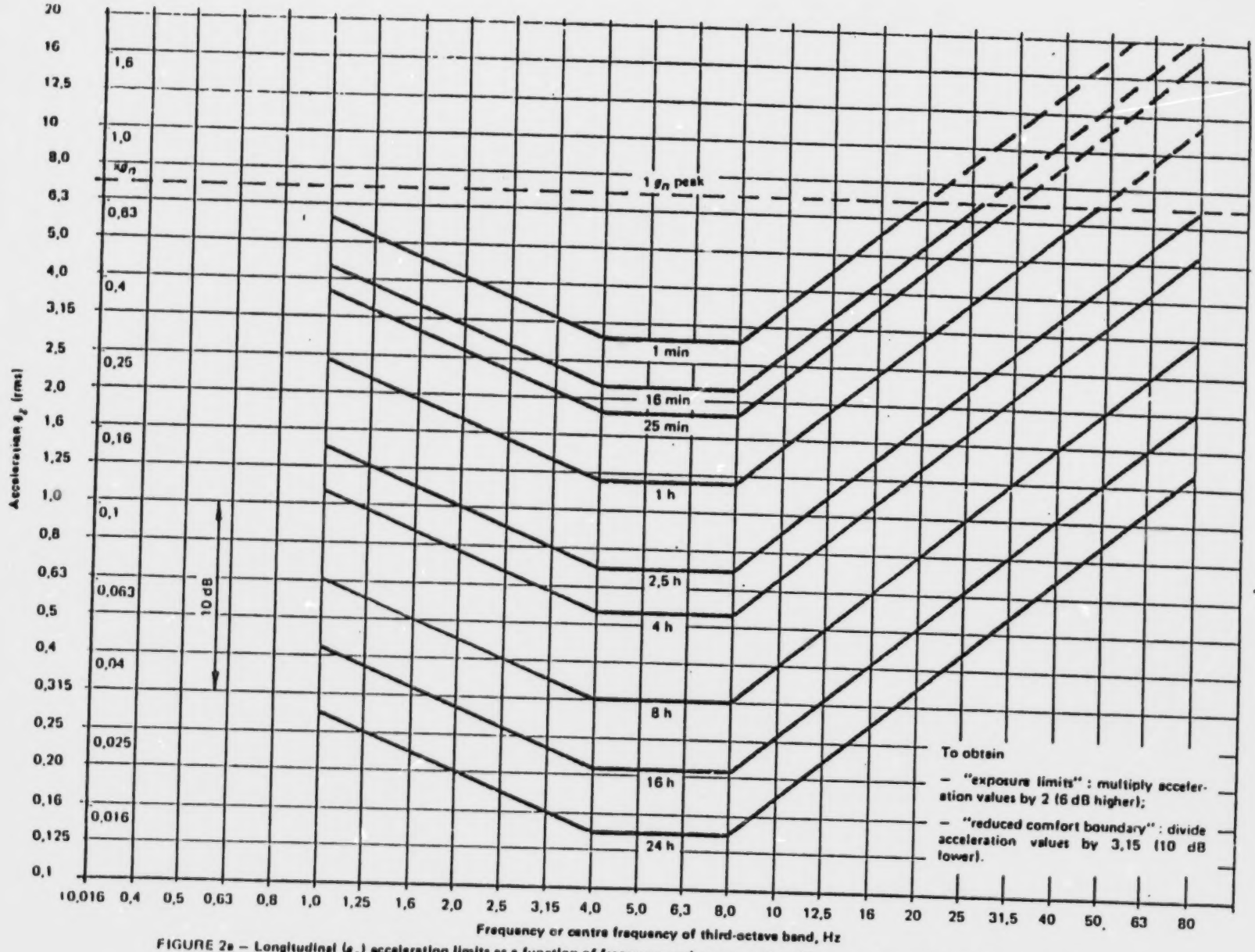


FIGURE 2a – Longitudinal (a_z) acceleration limits as a function of frequency and exposure time; "fatigue – decreased proficiency boundary"

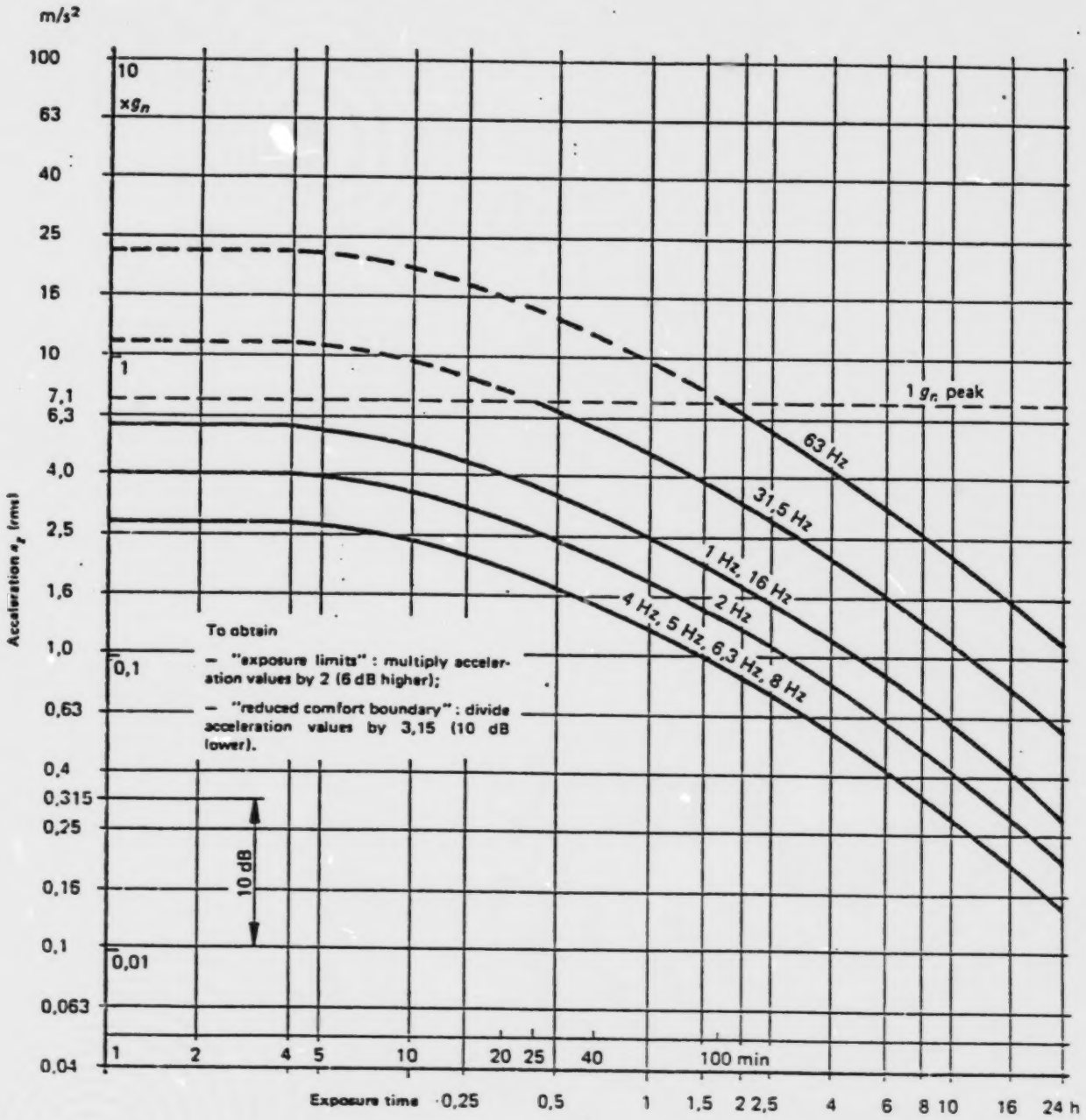


FIGURE 2b – Longitudinal (a_z) acceleration limits as a function of exposure time and frequency (centre frequency of third-octave band) : "fatigue – decreased proficiency boundary"

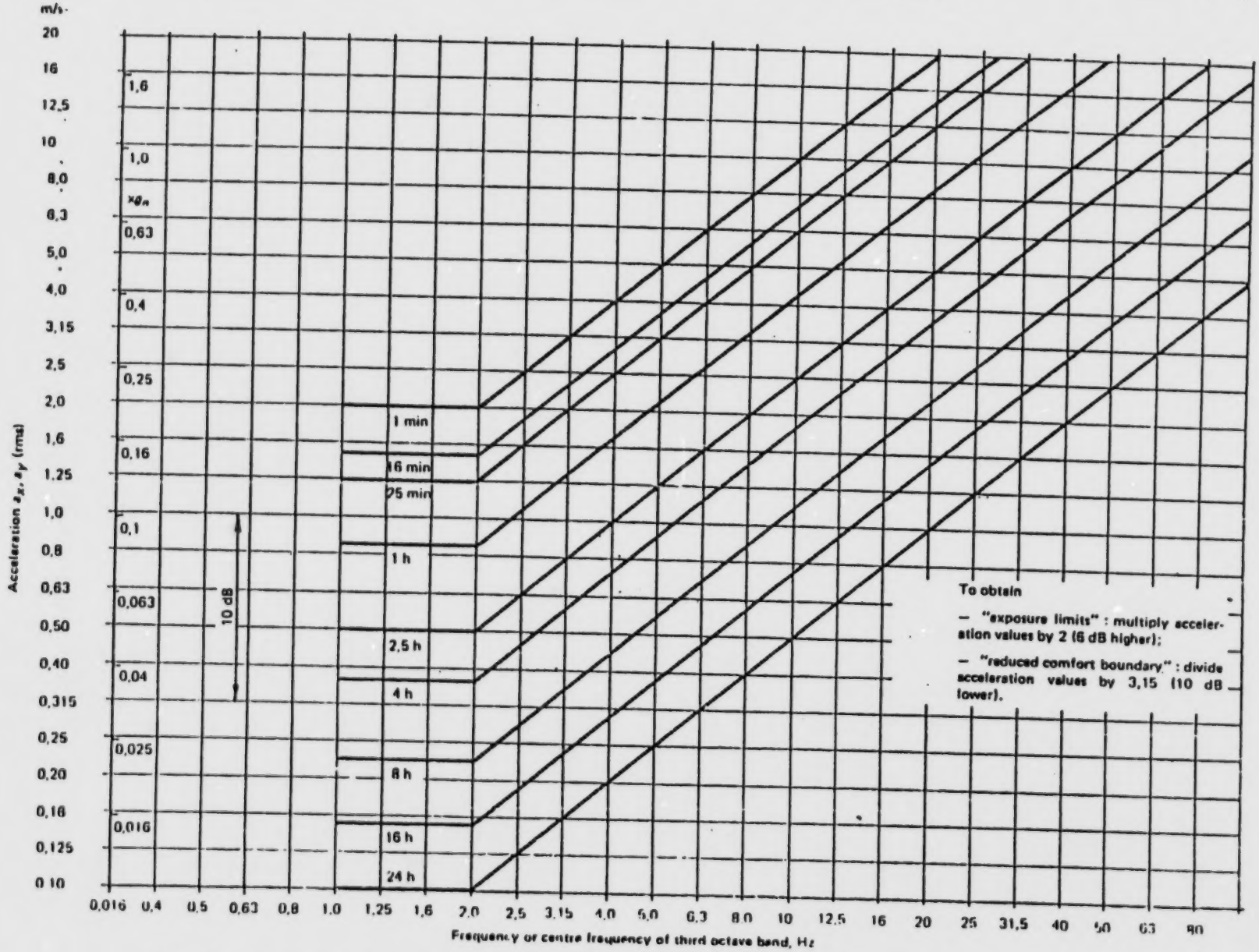


FIGURE 1a - Transverse (a_x, a_y) acceleration limits as a function of frequency and exposure time, "fatigue - decreased proficiency boundary"

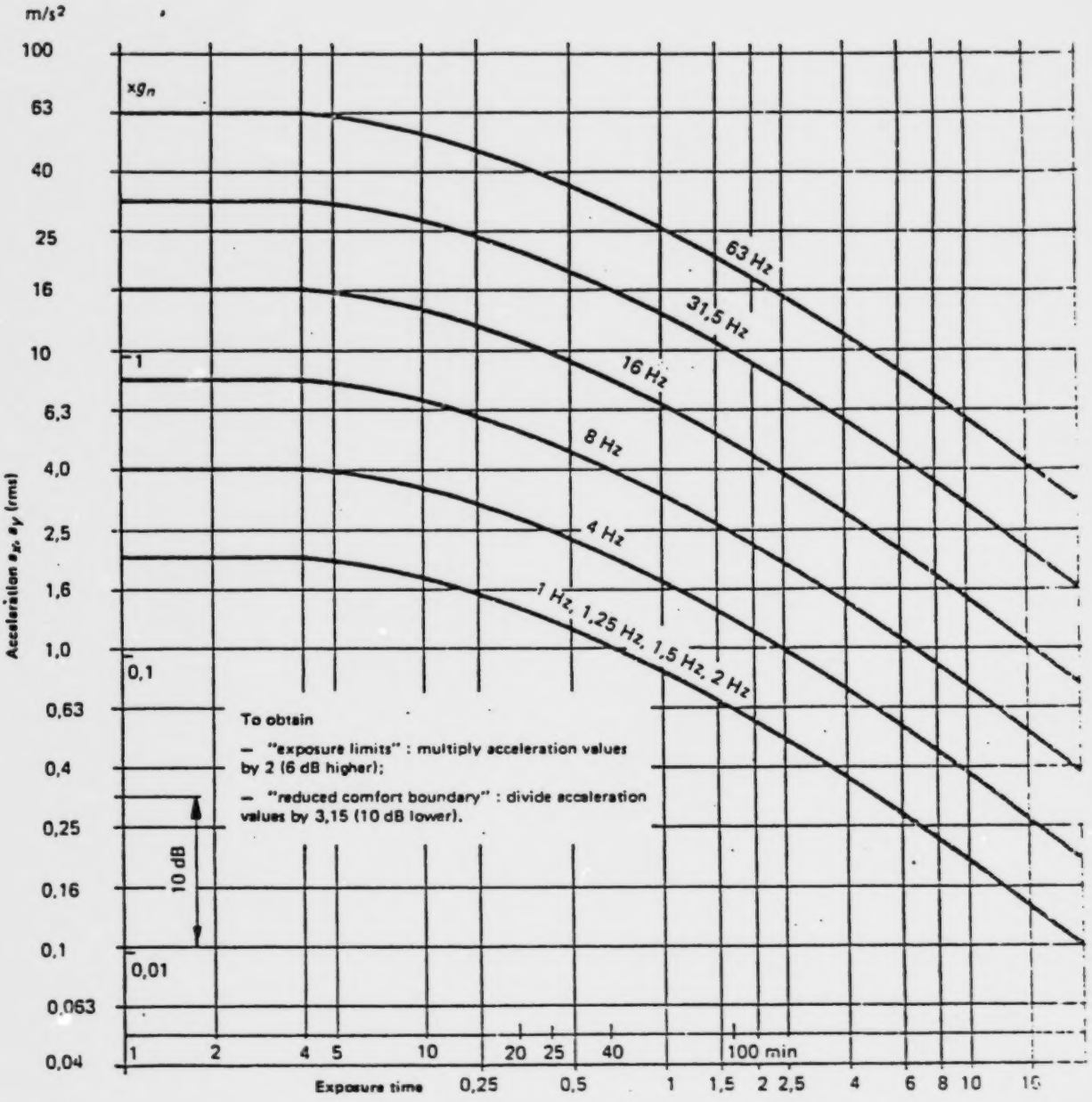


FIGURE 3c — Transverse (a_x, a_y) acceleration limits as a function of exposure time and frequency (or centre frequency of third-octave band "fatigue — decreased proficiency boundary"

APPENDIX B

Details on Track Geometry Defects characteristics used during the Perturbed Track Test performed at the Pueblo Transportation Test Center.

SUMMARY OF TRACK GEOMETRY IRREGULARITIES

Section No.	Zone (Tangent, or) (1.5° curve)	TRACK GEOMETRY IRREGULARITY DESCRIPTION			
		Type	Waveform	Wavelength (ft)	Amplitude (inches)
1	C	Cross-level	P.Lin.(1)	78	± ½"
2	C	Lateral (2)	P.Lin.	78	- 1"
3	C	Lateral (2)	Rect.sine	39	+ 1
4	C	Cross-level Lateral(2)	P.Lin. P.Lin.	78 78	± ½ - 1"
5	C	Lateral(H)(2)	Rect.sine	39	+ 1
6	T	Vertical	P.Lin.	78	+ 1½
7	T	Cross-level	P.Lin.	78	± ½
8	T	Lateral	P.Lin.(2)	78	- 1
9	T	Cross-level Lateral	P.Lin. P.Lin.(2)	78 78	± ½" - 1"

Notes: (1) Piecewise Linear. Waveform made from three straight rail sections.

(2) The lateral irregularity was present on both rails, except for section No. 5 where the irregularity was present only on the outer (high) rail at the curve.

APPENDIX B

TO

REPORT 438900-1

PROPOSED ANALYSIS METHODS

STEERABLE TRUCK PROJECT

BY

DSL DYNAMIC SCIENCES LTD.

Project C 220-2

PROPOSED ANALYSIS METHODS

STEERABLE TRUCK PROJECT

by

DSL DYNAMIC SCIENCES LIMITED

for

BOMBARDIER LTD.
Rail & Diesel Product Division

C220-2
May, 1982

1. SCOPE

This report describes the proposed techniques which will be used to perform the various dynamic performance evaluations.

2. DESCRIPTION OF THE PROPOSED DYNAMICS ANALYSIS METHODS

The feasibility and applications of the proposed locomotive dynamics analysis method have been demonstrated previously*. This approach represents to our knowledge the most up-to-date technique with respect to its ability to represent detailed suspension design features typical of North American locomotives. This was made necessary in the methodology development by the need to accept suspension characteristics data as measured under laboratory test on several actual locomotive trucks.

When dealing with actual suspension hardware details, the model design concept and the selection of degrees of freedom is critical in producing an analysis tool that maximizes benefits to the locomotive truck designers. This selection must be such as to produce best accuracy at lowest burden in numerical computation requirements. Based on a preliminary examination of the existing locomotive configuration, a list of design features has been prepared. The list in Table 1 is preliminary, since a detailed analysis of the trucks and suspension system has not yet been performed. However, it represents design features that have already been represented in existing DSL models, or which are considered as relatively straightforward additions.

---

* Methodology Development for the Derailment Safety Analysis of Six-Axle Locomotives/Technical Report, May 1982.
DSL Dynamic Sciences Limited, and Martin Marietta Corporation, Denver Aerospace.

TABLE 1 FEATURES OF THE LOCOMOTIVE MODEL

Secondary Suspension Elements:

- Truck rotational stiffness.
- Lateral shear rate of the rubber pads including the inclined traction pads.
- Lateral travel and bump stop characteristics.
- Hydraulic or Friction dampers.

Primary Suspension Elements:

- Vertical stiffness.
- Vertical travel and bump stop characteristics.
- Hydraulic or Friction dampers.
- Vertical pedestal friction.
- Lateral stiffness.
- Lateral pedestal clearance.
- Lateral pedestal friction.

Wheel-Rail Interaction

- Tapered wheel treads.
- Flange contact.
- Adhesion limited creep forces.
- Lateral rail stiffness.

Miscellaneous other Features

- Axle to axle diameter mismatch.
- Tape size mismatch on a wheel pair.

Operational Conditions

The list below represents operational conditions that will be considered in the analysis of locomotive dynamic response.

- Speed.
- Track curvature and superelevation.
- Tractive effort.
- Dynamic brakes.
- Brake shoe forces.
- Coupler forces.
- Track geometry irregulatities in alignment, cross-level, surface and gauge.

3. SAMPLE RESULTS FROM THE EXISTING MODEL

The following figures represent sample computer printouts and analysis results obtained from the existing dynamic locomotive model. Figure A-1 represents a partial list of locomotive parameters relating to the suspension properties. Figure A-2 is a plot representing the vertical response of the locomotive body resulting from a simulated Drop Test of two inches (note that the linear decay envelope is typical of systems having friction damping). Figure A-3 represents the results of a parametric study on the effect of lateral dampers in the secondary suspension (note that the effect is dependent on the locomotive tractive effort).

SAMPLE PARAMETER LIST

SUSPENSION PROPERTIES				
SECONDARY				
LATERAL				
STIFFNESS				
RUBBER STIFFNESS		LB/IN	15500.	69
SPRING TRAVEL TO STOP(EACH SIDE)		IN	1.250	70
STIFFNESS BEYOND STOP		LB/IN	150000.	71
DAMPING				
VISCOUS COEFFICIENT (RUBBER)		LB/(IN/SEC)	136.	72
FRICTION BOLSTER COEFFICIENT		—	.40	73
LVB COEFFICIENT FOR BOLSTER FRICTION		LB/(IN/SEC)	4000.	74
YAW DAMPING				
ROTATIONAL FRICTION FACTOR		IN-LB/LB	1.10	75
LVB COEFFICENT		IN-SEC	10000000.	76
EXTERNAL DAMPERS				
VISCOUS COEFFICIENT		LB/(IN/SEC)	1020.	77
LIMITING FORCE		LB	3500.	78
PRIMARY				
LATERAL				
STIFFNESS				
ROLLER BEARING FREE PLAY		IN	.31	79
RUBBER ELEMENTS TRAVEL		IN	.25	80
RUBBER PRELOAD		LB	1500.	81
STIFFNESS BEYOND STOP		IN	100000.	82
DAMPING				
FRICTION FOR ROLLER BEARING		—	.10	83
LVB COEFFICIENT FOR FRICTION		LB/(IN/SEC)	4000.	84
VERTICAL				
STIFFNESS				
AVAILABLE TRAVEL(COMPRESSION)		IN	2.25	85
AVAILABLE TRAVEL(EXTENSION)		IN	2.25	86
SPRING STIFFNESS(PER JOURNAL)		LB/IN	5630.	87
STIFFNESS BEYOND STOP(EITHER WAY)		LB/IN	200000.	88
PEDESTAL DAMPING				
FRICTION COEFFICIENT(PEDESTAL FACE)		—	.35	89
FRICTION COEFFICIENT(SIDE LUG)		—	.35	90
LVB COEFFICIENT FOR TOTAL FRICTION		LB/(IN/SEC)	3000.	91
EXTERNAL DAMPERS (OPTIONAL)				
CODE TO INDICATE THE PRESENCE OR ABSENCE OF EXTERNAL DAMPERS (0=NO DAMPER) (1=DAMPER)	LEFT AXLE 1	—	0.	92
	2	—	1.	93
	3	—	0.	94
	4	—	0.	95
	5	—	1.	96
	6	—	0.	97
	RIGHT 1	—	0.	98
	2	—	1.	99
	3	—	0.	100
	4	—	0.	101
	5	—	1.	102
	6	—	0.	103
VISCOUS COEFFICIENT (COMPRESSION)		LB/(IN/SEC)	510.	104
VISCOUS COEFFICIENT(EXTENSION)		LB/(IN/SEC)	510.	105
LIMITING FORCE(COMPRESSION)		LB	1800.	106
LIMITING FORCE(EXTENSION)		LB	1800.	107
WHEEL/RAIL				
FLANGE				
FLANGEWAY CLEARANCE(EACH SIDE)		IN	.550	108
STIFFNESS AFTER FLANGE CONTACT		LB/IN	80000.	109
TREAD				
CREEP COEFFICIENT ADJUSTMENT FACTOR		—	.70	110
COULOMB FRICTION COEFFICIENT		—	.30	111

FIGURE A-1

SAMPLE OUTPUT PLOT

FREE DAMPED RESPONSE/

LOCOMOTIVE BODY VERTICAL

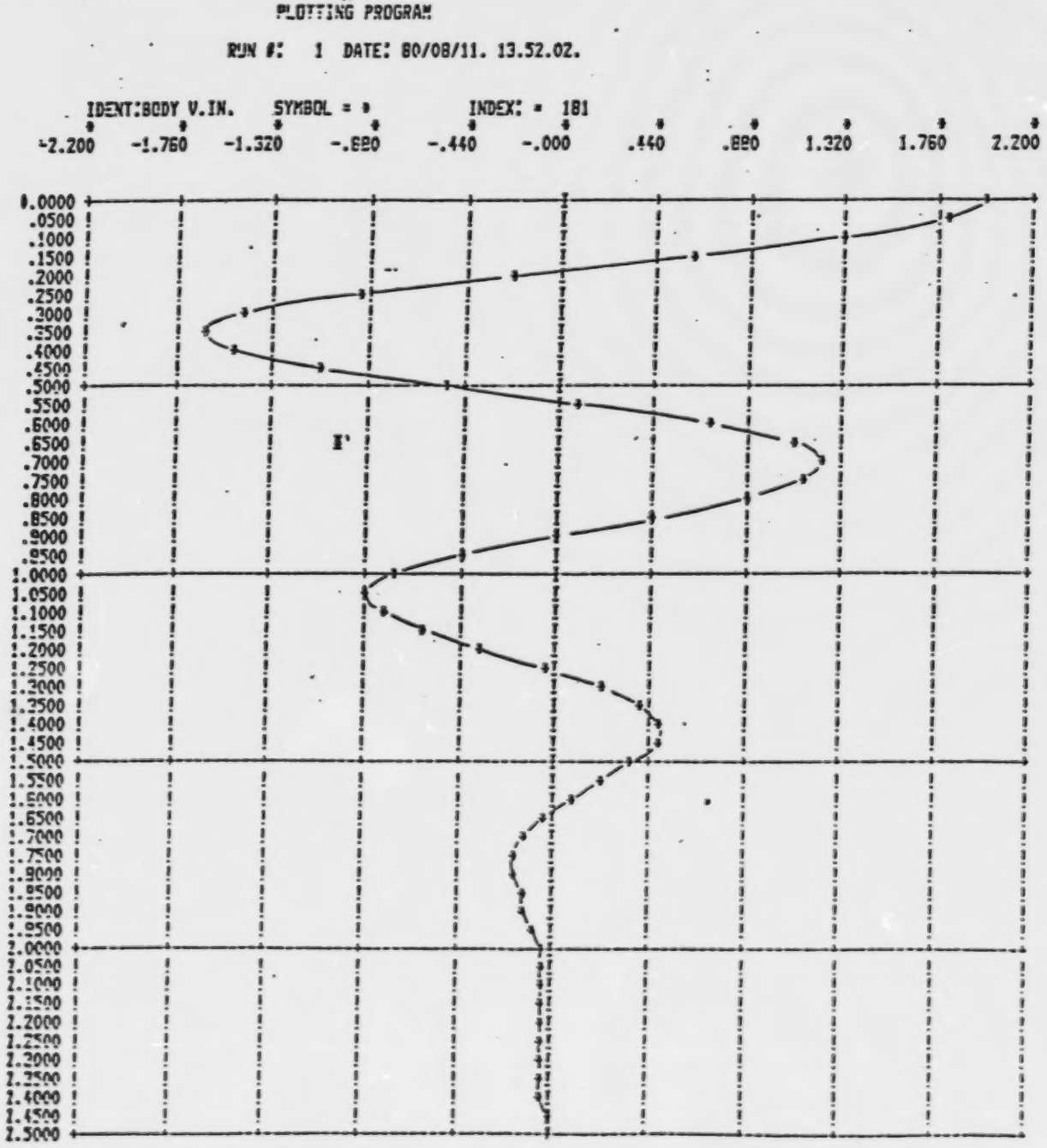


FIGURE A-2

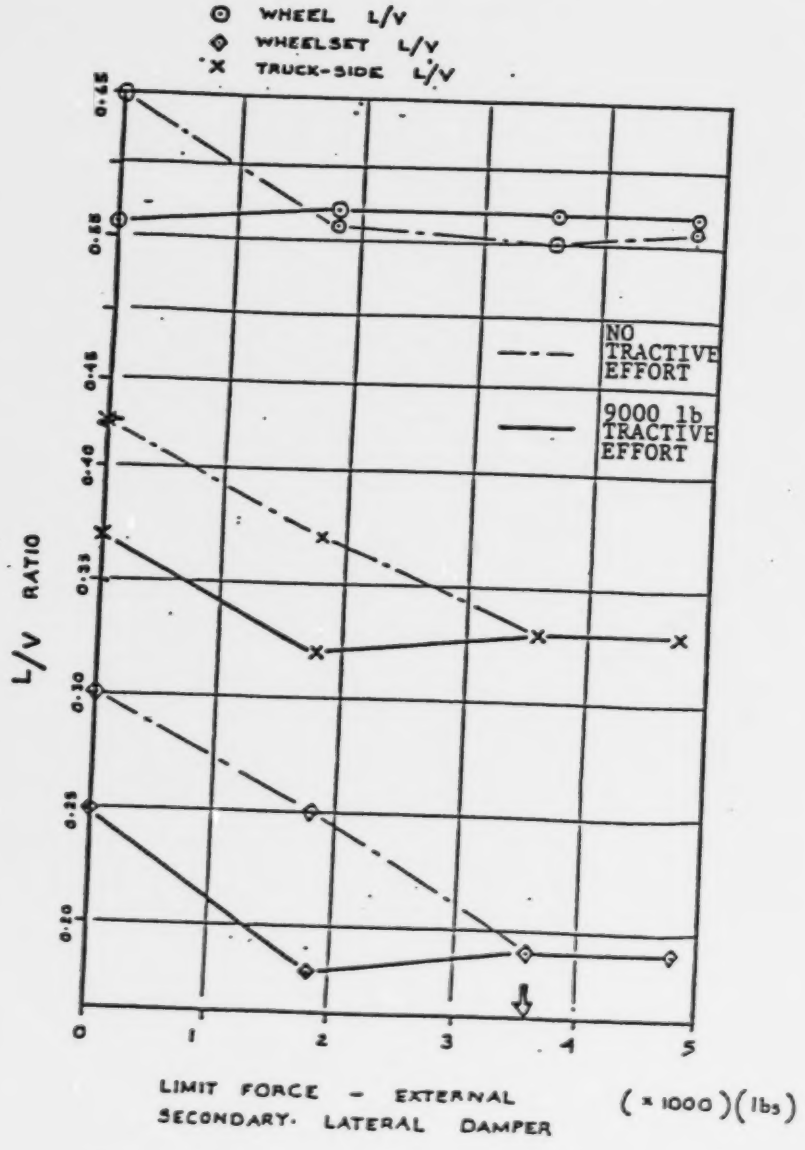

WHEEL L/V
WHEELSET L/V
TRUCK-SIDE L/V
NO TRACTIVE EFFORT
9000 lb TRACTIVE EFFORT
L/V RATIO
0.45
0.38
0.43
0.40
0.33
0.30
0.25
0.20
0
1
2
3
4
5
LIMIT FORCE - EXTERNAL SECONDARY. LATERAL DAMPER
(x 1000)(lbs)

FIGURE A-3

APPENDIX C

TO

REPORT 438900-1

STEERABLE TRUCK PROJECT

Fig.1 REFERENCE TRUCK ARRANGEMENT
Fig.2 FLEX TRUCK ARRANGEMENT
Fig.3 TEST LOCOMOTIVE ARRANGEMENT

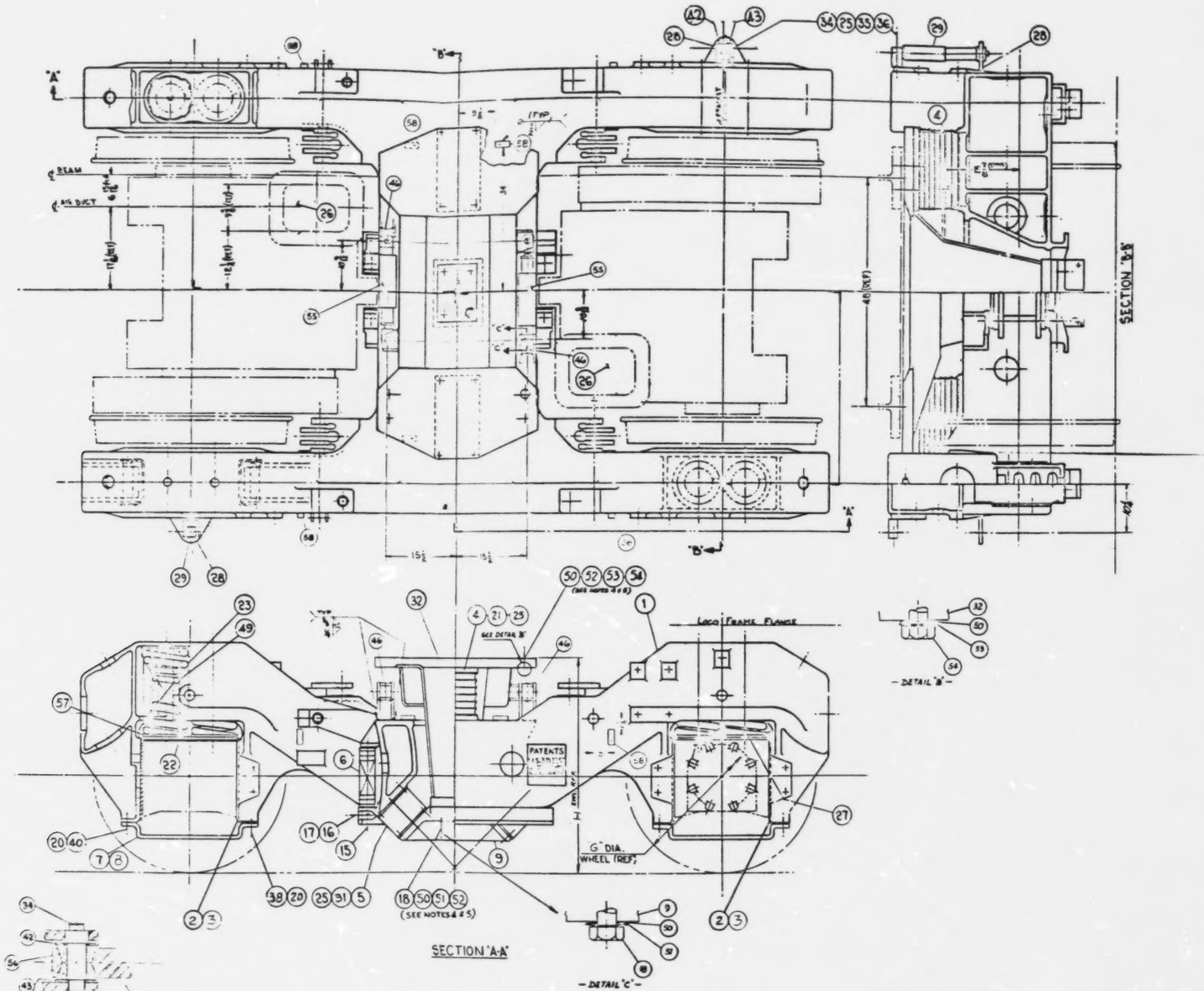
APPENDIX D

TO

REPORT 438900-1

WORK STATEMENTS

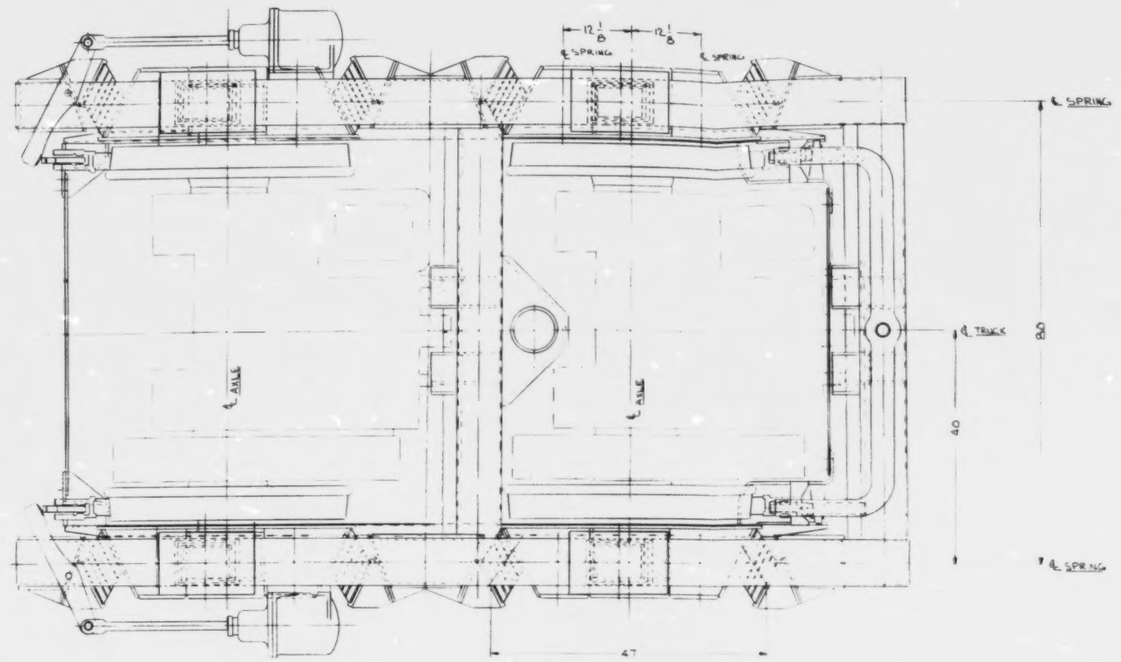
D-1 Bombardier Work Statement
D-2 DSL Work Statement
D-3 REA Work Statement

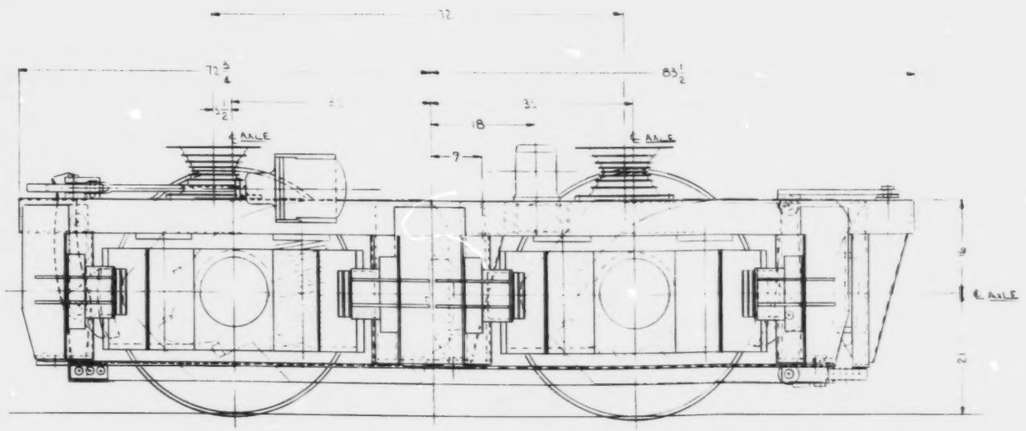


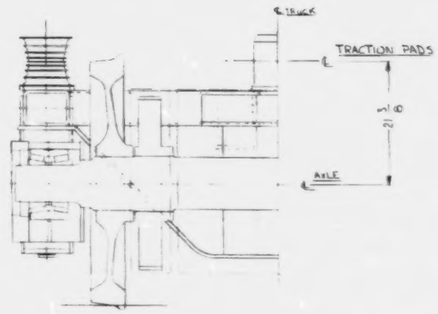
DE	1	A41-061360-090	FRAME MACH
B7	2	641-091345-090	PLATE LH
B5	3	641-061307-030	PED LINER
D6	4	972-011260-501	METALASTIC
B6	5	972-011260-504	METALASTIC
C6	6	641-092770-080	HT HOSE SHR
K7	7	1641-053620-000	CAP PEDSTL
C7	8	641-092280-000	CAP PEDSTL
C6	9	641-090220-000	BASE
	10		
	11		
	12		
	13		
	14		
C6	15	641-097780-000	PIN HT HOSE
K7	16	641-091032-000	PIN KEEP
C7	17	928-079007-048	PIN COTTER
B5	18	928-011637-148	BOLT
	19		
B7	20	91P-064005-026	NUT
D6	21	928-011627-040	CAP SCREW
C7	22	641-090101-000	SEAT SPR
D7	23	N76-004381-030	SPR COIL
	24		
D6	25	91P-083504-027	LOCKWASHER
G7	26	641-090370-000	AIR DUCT TH
C4	27	972-011640-524	PAD ERS HSG
D7	28	641-090091-000	SEAT SPR
D7	29	972-043365-009	ABSOR SHOE
	30		
B6	31	928-015066-048	SCREW SOC
D4	32	A41-092500-000	POST LTR
	33		
H4	34	972-011640-544	PIN SHOE
H4	35	91P-061630-022	NUT
H4	36	928-079005-048	PIN COTTER
	37		
B7	38	115-001430-000	C/SCREW
	39		
C8	40	115-001431-000	C/SCREW
	41		
H5	42	641-090420-000	WASHER INR
H5	43	641-090421-000	WASHER OUTR
	44		
	45		
D6	46	A40-005390-000	BRKT SHOE
	47		
	48		
D7	49	972-004362-000	SPRING COIL
B6	50	641-090810-000	BAR
B6	51	641-090823-000	SHEET
B5	52	700-43-01109-045	GREASE
D4	53	641-091070-000	SHEET
D4	54	928-011637-184	BOLT
B7	55	972-026900-104	SHUBBER
B8	56	641-006630-000	BUSHING
D8	57	930-580710-217	SPR SEAT IND
C5	58	641-090422-000	SUPPORT
	59		
	60		

APPENDIX "C"
FIG. 1 – REF. TRUCK ARRG'T.

Fruehauf Corp. — MOTOR TRUCK ARRANGEMENT — A40-005810-000







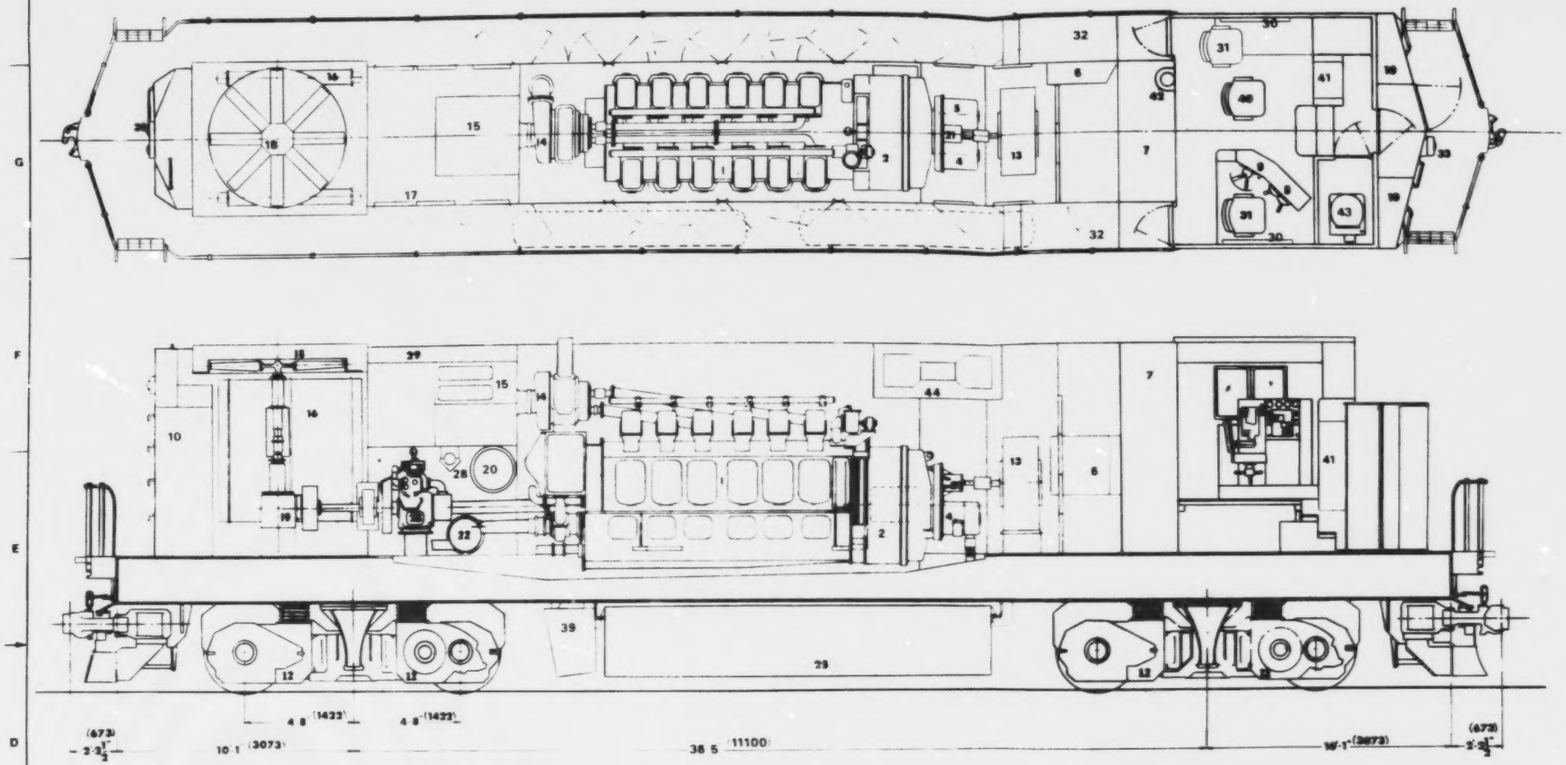
APPENDIX "C"
FIG. 2 – FLEX. TRUCK ARRG'T.

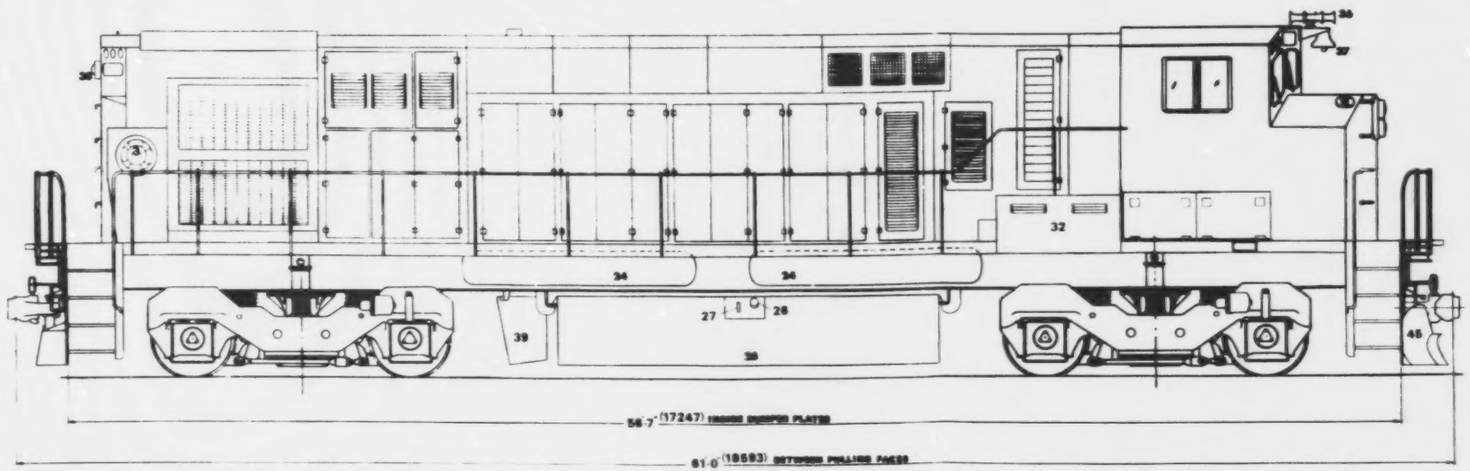
MSK-O-5549

Bombardier Inc.
Division des produits ferroviaires et diesel
Rail and Diesel Products Division
Montréal Québec Canada

2 AXLES FLEX-TRUCK
ARRANGEMENT

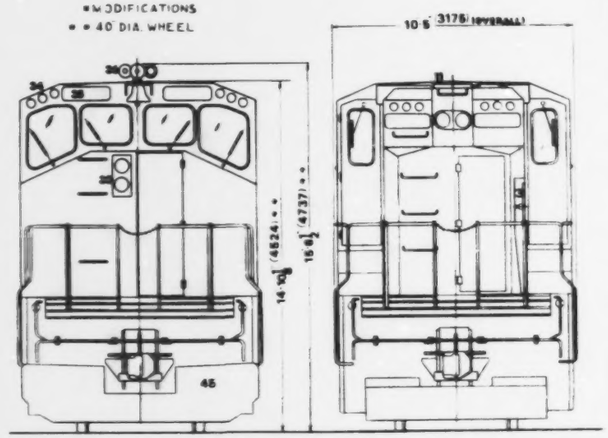
Commande Sales Order No. 438930
Scale 1/8
Size A0
Drawing No. MSK-O-5549





1 - ENGINE
2 - MAIN ALTERNATOR
3 - HAND BRAKE
4 - AUXILIARY GENERATOR
5 - EXCITER
6 - RECTIFIERS
7 - CONTROL COMPARTMENT
8 - CONTROL STAND
9 - BRAKE STAND
10 - SAND BOX
11 - SAND BOX FILL
12 - TRACTION MOTOR
13 - BLOWER TRACTION MOTOR
14 - TURBO SUPERCHARGER
15 - ENGINE AIR INTAKE FILTERS-SECONDARY
16 - RADIATOR
17 - ENGINE AIR INTAKE FILTERS-PRIMARY
18 - RADIATOR FAN
19 - RADIATOR FAN CLUTCH
20 - LUBRICATING OIL FILTER
21 - GEAR UNIT-BLOWER DRIVE
22 - LUBRICATING OIL COOLER
23 - AIR COMPRESSOR
24 - MAIN AIR RESERVOIR
25 - FUEL TANK
26 - FUEL TANK FILLING CONNECTION
27 - FUEL TANK GAUGE
28 - FUEL OIL FILTER
29 - ENGINE WATER EXPANSION TANK
30 - CAB HEATER
31 - CAB SEAT
32 - BATTERIES
33 - HEADLIGHT
34 - CLASSIFICATION LIGHT
35 - NUMBER BOX
36 - HORN
37 - BELL
38 - BACK-UP LIGHT
*39 - POLLUTION TANK
*40 - CAB SEAT
*41 - REFRIGERATOR
*42 - HOT PLATE
*43 - TOILET
*44 - DYNAMIC BRAKE
*45 - SNOWPLOW

*MODIFICATIONS
* 40" DIA. WHEEL



APPENDIX "C"
FIG. 3 – TEST LOCO. ARRG'T.

GENERAL ARRANGEMENT
A0 A98-093820-000

A98-093820-000

APPENDIX

BOMBARDIER INC.

May 31, 1982

2 AXLE LOCOMOTIVE

STEERABLE TRUCK PROJECT

WORK STATEMENT

STATEMENT OF WORK

1.0 Introduction & Background.

1.1 A steerable locomotive truck offers the potential for improved performance in several areas, including improved curving, improved traction adhesion in curves, and improved stability.

1.2 Several developments are presently underway in North America to apply steering trucks to rail vehicles. To date, this work has been limited to freight cars and transit vehicles.

1.3 Bombardier have completed a feasibility study, working with Mr. Harold List, to apply some of the List steering principles to a locomotive truck.

1.4 It is possible that, for a railway locomotive in a typical application, improved curving performance can be achieved with a rigid frame truck with properly selected longitudinal and lateral primary suspension rates.

1.5 Bombardier, with its truck expertise, test locomotive and manufacturing capability, is in a unique position to manage a program to select a candidate steerable truck design for manufacture and test. It would propose to work closely with Dynamic Sciences Limited (DSL) in developing criteria and performing mathematical analysis of the candidate designs.

1.6 Service contract No. 4717 has been awarded by Transport Canada Development to cover the following initial work on this project:

1.6.1 Make the necessary subcontractual arrangements with Dynamic Sciences Limited (DSL) and Mr. List to fulfill the project requirements.

1.6.2 Define and develop a detailed list of criteria that can be used to evaluate the candidate design groups.

1.6.3 Elaborate on the techniques which will be used to perform the various evaluations and identify the key parameters being sought.

1.6.4 Draw up plans and work statements for inclusion into a detailed plan for the total development program. The program shall cover all phases from the initial basic design selections to the completed hardware development and testing phase.

1.6.5 Perform a SPEC planning session to finalize the detailed planning effort.

1.7 This statement of work summarizes the further work required to:

1.7.1 Develop the candidate designs.

1.7.2 Evaluate the potential performance of each candidate design.

1.7.3 Compare the candidate designs with each other and with a standard zero weight transfer truck.

2.0 Scope

2.1 Objective.

The objective of this program is to determine the most feasible design for a 2 axle locomotive steerable truck from the point of view of cost, practicality and performance, prepare a preliminary design of the truck, and establish its theoretical performance, using modern mathematical techniques. This truck will then be compared with a conventional locomotive truck, using the same evaluation criteria.

2.2 Criteria.

Performance criteria will be developed to evaluate candidate truck designs. This will include both performance and practical (cost benefit) considerations.

2.3 Candidate Designs.

Three basic designs will be evaluated as follows:

i) rigid frame truck with improved curving obtained through proper selection of lateral and longitudinal primary suspension rates. (Bombardier design)

ii) radial arm type crossed braced truck (List principle).

iii) "baseline" conventional 2 axle locomotive truck.

Layout, component hardware selection, and design loads will be established for the candidate designs.

2.4 Rights.

The study will include the application of some of Mr. List's patented principles to a locomotive truck design. Selection of the List design for subsequent manufacture and test will be contingent upon a satisfactory agreement being reached between Mr. List and Bombardier concerning manufacturing rights and royalties.

2.5 Responsibilities.

Bombardier will have right of final selection of the most suitable design. Selection will be made by a panel of senior Bombardier locomotive engineers.

DSL will be the designated analytical authority, will consult with all parties concerned, but will make the final recommendations to Bombardier concerning performan ce.

Candidate designers will use their own mathematical capabilities to optimize their designs. These designs will be submitted to Bombardier and DSL. DSL will analyze all candidate designs using DSL models.

3.0 Definition of Tasks

The first two tasks of this project

Task 1 - preparation of detailed work plan
Task 2 - development of evaluation criteria

will be accomplished under Service Contract 4717.

Further tasks to complete the project are:

Task 3 - Design

The design groups will develop their respective designs and complementary mathematical analysis.

They will develop a truck layout, specify all component hardware, and establish design loads in all component members.

The design and back-up documentation will be submitted to Bombardier for analysis.

Task 4 - Analysis Capability Development

DSL will develop a generalized program capable of analyzing all candidate truck designs. This will be based, to the greatest extent possible, on existing models already developed.

APPENDIX

Task 5 - Design Evaluation

Bombardier will evaluate all designs on the basis of practical feasibility (cost, maintainability, weight, weight transfer, etc., etc.) using data supplied by the subcontractors as a basis.

DSL will evaluate all designs on the basis of calculated performance, using the model developed in Task 4, and prepare a summary report for submission to Bombardier.

Task 6 - Selection & Final Report

Bombardier will select the candidate steerable truck to be advanced to the detailed design, manufacture and test phase, and will prepare a complete report including the various layout designs, and design analysis, and justification for the design selection.

4.0 Deliverables.

1. Report on Mathematical Analysis.

2. Final Project Report.

PROJECT PLAN

STEERABLE TRUCK PROJECT

prepared by

DSL DYNAMIC SCIENCES LIMITED

for

BOMBARDIER LTD.
Rail & Diesel Product Division

C220-3, May 1982

SCOPE

This project plan relates to the DSL portion of the work to be achieved under the "Two-Axle Locomotive Steerable Truck Project".

This report has been arranged in parts as follows:

Part 1

General Project Arrangement.

This section lists the main subtasks of the project, and gives information on the scope and objectives of each. It is included to explain the planned general conduct of the project.

Part 2

This section contains the work breakdown structure, the projected manpower allocations and schedule.

PART 1 TASK DESCRIPTIONS

000 Project Monitor

010 Job Control

This includes internal control of progress and project resources, as well as the preparation of periodic progress reports.

020 Technical Reports

This activity covers review and editing of the various technical reports to be produced.

030 Interface with Others

This includes the various ad hoc activities involved in interfacing with other parties such as the arrangements of meetings, collection of data and the technical interchange meetings with Bombardier and the design groups.

400* ANALYSIS CAPABILITY DEVELOPMENT

The objective of this task is to adapt the existing methodology to analyze the three candidate truck designs on a common basis. This task has been divided in two, Model Design, and Methodology Implementation.

410 Model Design

The model design phase consists of defining mathematical forms for all technical data related to locomotive dynamic performance analysis. The various items are classified as follows:

411 "Reference Truck" Model

412 "Flex Truck" Model

413 "List Truck" Model

414 Operational Conditions Models

415 Performance Evaluation Models

416 Engineering Analysis

The modelling tasks essentially consist in collecting and reviewing hardware related data with a view to define physical and mechanical characteristics for computer simulation.

---

* The Task Numbering System used in this plan is based on the original Bombardier Work Statement dated 16 February, 1982.

Typically, the modelling task involving the locomotive and trucks include data on i) basic locomotive and trucks layout and geometry, ii) mass properties, iii) suspension element characteristics, iv) miscellaneous features specific to the design.

Operational condition models consider aspects which are external to the locomotive design as such. These include track geometry (basic layout and track irregularities), wheel-rail interaction effects, coupler forces, speed effects, and other effects relating to the use of traction or brakes.

Performance evaluation models consider means to evaluate performance indices relating to traction, safety, ride and others as determined from Task 2. For example, operational safety related aspects require models for derailment mechanisms as well as track failure mechanisms.

The manpower estimates for the modelling tasks have been produced for normal expected progress, without account for special problems. Judging from experience, cases are found where data is not available, or available data is not believed to be truly adequate for dynamic representation. For example, only the strength but not the stiffness value of a given structural element may be relevant to the design team. Also, manufacturer's data may only be available for quasi-static conditions which may not be typical of dynamic conditions. (e.g. elastomeric elements). These activities are collected in the Engineering Analysis task.

420 Methodology Implementation

All modelling information is in the existing computer programs, to provide means to evaluate each locomotive and to compare them on uniform evaluation criteria.

This is subdivided into the following subtasks.

421 Requirements Definition

422 Preliminary Design

423 Final Design

424 Implementation

425 Test

426 Summary Report

Requirements definitions will outline in detail, the scope and features to be implemented in the computer program. It will also include a specification of all input parameters and output formats.

Preliminary Design includes the preparation of structure charts symbols dictionaries, and lists of subroutines and functional descriptions of processes. Preliminary design also specifies test and debugging methods to be used at completion of program implementation.

Final Design implementation and test concern the actual software development work.

At completion, a summary report is prepared outlining the description and results of the software tests.

500 Design Evaluation

This phase will establish the comparative performance of the three candidate trucks, using the methodology described in Task 4. The subtasks are used.

510 Performance Evaluation
- 511 Baseline Truck
- 512 New "Bombardier" Design
- 513 New "List" Design

520 Comparative Analysis
- 521 Comparative Performance
- 522 Sensitivity and Interpretation
- 523 Summary Report

Evaluation of each truck will be done according to the established procedures and the various performance indices will be produced for each candidate truck. A report will be produced for each. Comparative Assessment of the three trucks will be performed concerning the most important or significant differences. Interpretation for the observed differences will probably require to carry out more simulation in the form of parameter sensitivity analysis and to retrieve from the simulations time histories of various variables not normally outputted. Interpretation may also require discussions with Bombardier and the various design groups.

A summary report of the comparative analysis will be prepared.

600 Selection and Final Report

610 Performance Analysis Summary

A project summary will be prepared, highlighting major aspects of the modelling, the methodology used and the results which are to be integrated into Bombardier's Final Report.

PART 2

WORK BREAKDOWN STRUCTURE AND PROJECTED RESOURCE ALLOCATIONS

WORK BREAKDOWN STRUCTURE

000 PROJECT MONITOR

- 101 Job Control
- 020 Technical Reports
- 030 Interface with Other Parties

400 ANALYSIS CAPABILITY DEVELOPMENT

- 410 Model Design
  - 411 Reference Truck
  - 412 Flex Truck
  - 413 List Truck
  - 414 Operational Conditions
  - 415 Performance Evaluation
  - 416 Engineering Analyses
- 420 Methodology Implementation
  - 421 Requirements Definition
  - 422 Preliminary Design
  - 423 Final Design
  - 424 Implementation
  - 425 Test
  - 426 Summary Report

500 DESIGN EVALUATION (DSL PORTION)

- 510 Performance Evaluation
  - 511 Reference Truck
  - 512 Flex Truck
  - 513 List Truck
- 520 Comparative Analysis
  - 521 Comparative Performance
  - 522 Sensitivity and Interpretation
  - 523 Summary Report

600 SELECTION AND FINAL REPORT (DSL PORTION)

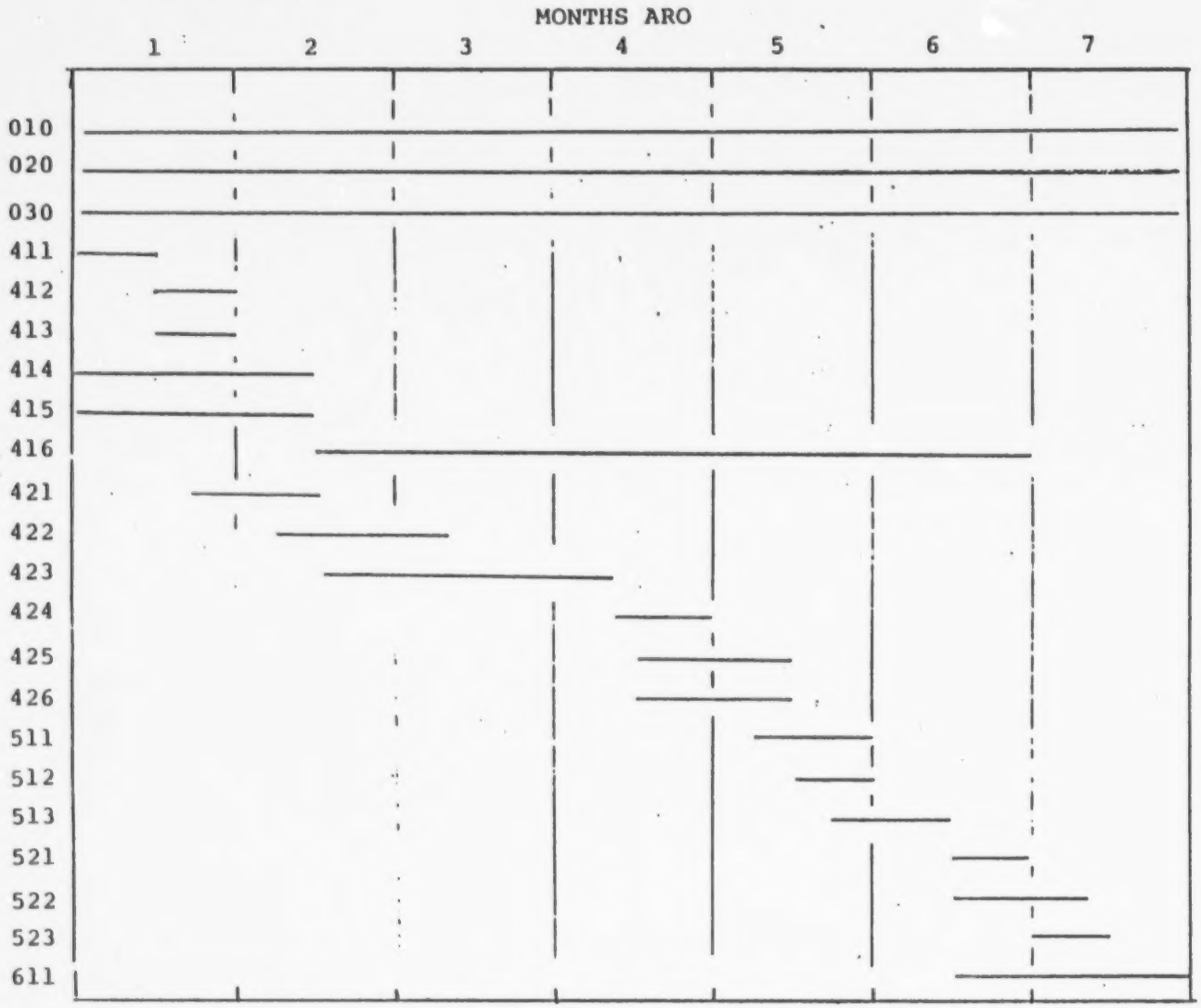
- 610 Performance Analysis Summary

PROJECTED ALLOCATION OF RESOURCES

The following table outlines the projected allocation of resources in man-weeks, considering average anticipated levels of personnel qualifications.

000	PROJECT RESOURCES	6
410	MODELLING	21
420	METHODOLOGY IMPLEMENTATION	34
510	PERFORMANCE EVALUATION	13
520	COMPARATIVE ANALYSIS	11
610	SUMMARY REPORT	4

SCHEDULE/C220



STEERABLE TRUCK PROJECT

REA WORK STATEMENT

- o Assist with project planning and reporting.
- o Supervise the design of the steerable truck hardware.
- o Make computer simulations of expected truck performance to select key truck parameters.
- o (Optional). Make computer simulations of the expected performance of either the 'reference' truck or the 'flexible' truck.

REA will perform the design supervision at Bombardier.

REA will perform the computer simulation studies at Lehigh University and will supply the study results in report form to Bombardier. The computer studies will include simulation of high speed stability on straight track and tracking behaviour in typical railroad curves. These studies may also include simulation of the dynamic response to selected track defects.

H.A. List
HAL:jv

APPENDIX E

TO

REPORT 438900-1

SPEC DOCUMENTS

STEERABLE TRUCK PROJECT

SPEC A.F.D.A. BASE

AGREED FACTS, DECISIONS, AND ASSUMPTIONS
INFORMATION BASE FOR PLANNING AND CONTROL

TWO AXLE LOCOMOTIVE STEERABLE
TRUCK DEVELOPMENT PROGRAM - PHASE II

SYSTEMS SERVICES
MONTREAL, QUEBEC
JUNE 24, 1982
82-7119-A02

JPG/DR/KL

PARTICIPANTS

MAURICE AUDETTE	- TDC
HAROLD LIST	- (REA RAILWAY ENGINEERING ASSOC.)
PIERRE MARCOTTE	- DSL (DYNAMIC SCIENCES LTD.)
DAVE TAYLOR	- BOMBARDIER
PETER WHITBY	- BOMBARDIER
BOB YOUNG	- DSL

MODERATORS

JACQUES GIGUERE
DENIS ROUSSEAU

PURPOSE OF SESSION

PLAN PHASE II

DEVELOP:

- A·F·D·A· BASE
- GENERAL NETWORK OF ACTIVITIES
- RAC MATRIX
- VELOCITY DIAGRAM

DEFINITIONS:

LIST TRUCK

- HAS DIRECT INTERCHANGE OF LATERAL STEERING FORCES BETWEEN TWO AXLES

FLEX TRUCK

- RIGID FRAME WITH OPTIMIZED LATERAL AND LONGITUDINAL STIFFNESS IN PRIMARY SUSPENSION

REFERENCE TRUCK

- STANDARD TRUCK PLUS IMPROVED SECONDARY SUSPENSION

(FOR FREIGHT LOCOMOTIVE TRUCK)

BACKGROUND

PHASE II APPROVED
PHASE II IS FINANCED BY TDC & BOMBARDIER
NO STEERING COMMITTEE
CRITERIA FOR SELECTION DONE IN PHASE I

LOCO. STEERING TRUCKS DO NOT EXIST IN NORTH AMERICA
STEERING TRUCKS AVAILABLE IN GERMANY
LOCO. STEERING TRUCKS EXIST ON TRANSIT CARS

BOMBARDIER IS CONTRACTING TO TDC
LIST & DSL ARE SUBS OF BOMBARDIER - MLW

SIMULATION PERFORMANCE MODEL BEING CUSTOMIZED BY DSL
KEA AND BOMBARDIER HAVE COMPUTER MODELS FOR DESIGN PURPOSES

GOALS

DEVELOP BETTER FREIGHT LOCOMOTIVE
- SAFER
- BETTER RIDE (STABILITY IN STRAIGHT LINE)

MAXIMIZE TANGENTIAL TRACTION

REDUCE WEIGHT OF TRUCK

REDUCE MAINTENANCE ON TRUCK & TRACK

FUEL EFFICIENCY

OBJECTIVES

DEVELOPMENT OF 2 DESIGNS:
- LIST TRUCK AND FLEX TRUCK

OPTIMIZATION OF THE REFERENCE TRUCK

EVALUATE POSSIBLE BENEFITS FROM DESIGNS

SELECT MOST SUITABLE TRUCK

SELECTION BASED ON EVALUATION OF PERFORMANCE VERSUS COST & COMPLICATION

EVALUATION:
- PERFORMANCE OF TRUCKS EVALUATED THROUGH COMPUTER SIMULATION

COST EVALUATION:
- SUITABLE PRODUCTION BATCH OF EACH DESIGN
- EVALUATION OF MAINTAINABILITY

CONSTRAINTS

BUDGET

PROBLEMS

FUNDS FOR PHASE III

PHASING

PHASE I	PHASE II	PHASE III
DONE	DESIGN 2 STEERABLE LOCOMOTIVE BOOGIES	PRODUCTION & TESTING OF SELECTED DESIGN - (NO CONTRACT AS OF TODAY)
	DESIGN 2 CONCEPTS; EVALUATE WITH MODIFIED STANDARD TRUCK	
	PLAN PHASE III	

PHASE III - (ELEMENTS)

DETAILED DESIGN OF SELECTED TRUCK

IDENTIFY TESTING REQUIREMENTS

PLAN TEST PROGRAM

BUILD & MANUFACTURE TRUCKS

1ST TRUCK:
- STATIC TESTS
- FATIGUE TESTS
- RUN TEST PROGRAM ON PROTOTYPE

FABRICATE:
- 2ND TRUCK, LOCOMOTIVE
- 3RD TRUCK, LOCOMOTIVE
- RUN EXHAUSTIVE TESTS

TWO AXLE LOCOMOTIVE STEERABLE TRUCK - PHASE II 7119

JUNE 82		JULY 82		AUG 82	
PROJ WEEK	CALENDAR WEEK	PROJ WEEK	CALENDAR WEEK	PROJ WEEK	CALENDAR WEEK
1	20-26	3	4-10	7	1- 7
2	27- 3	4	11-17	8	8-14
	-	5	18-24	9	15-21
	-	6	25-31	10	22-28
	-		-		-

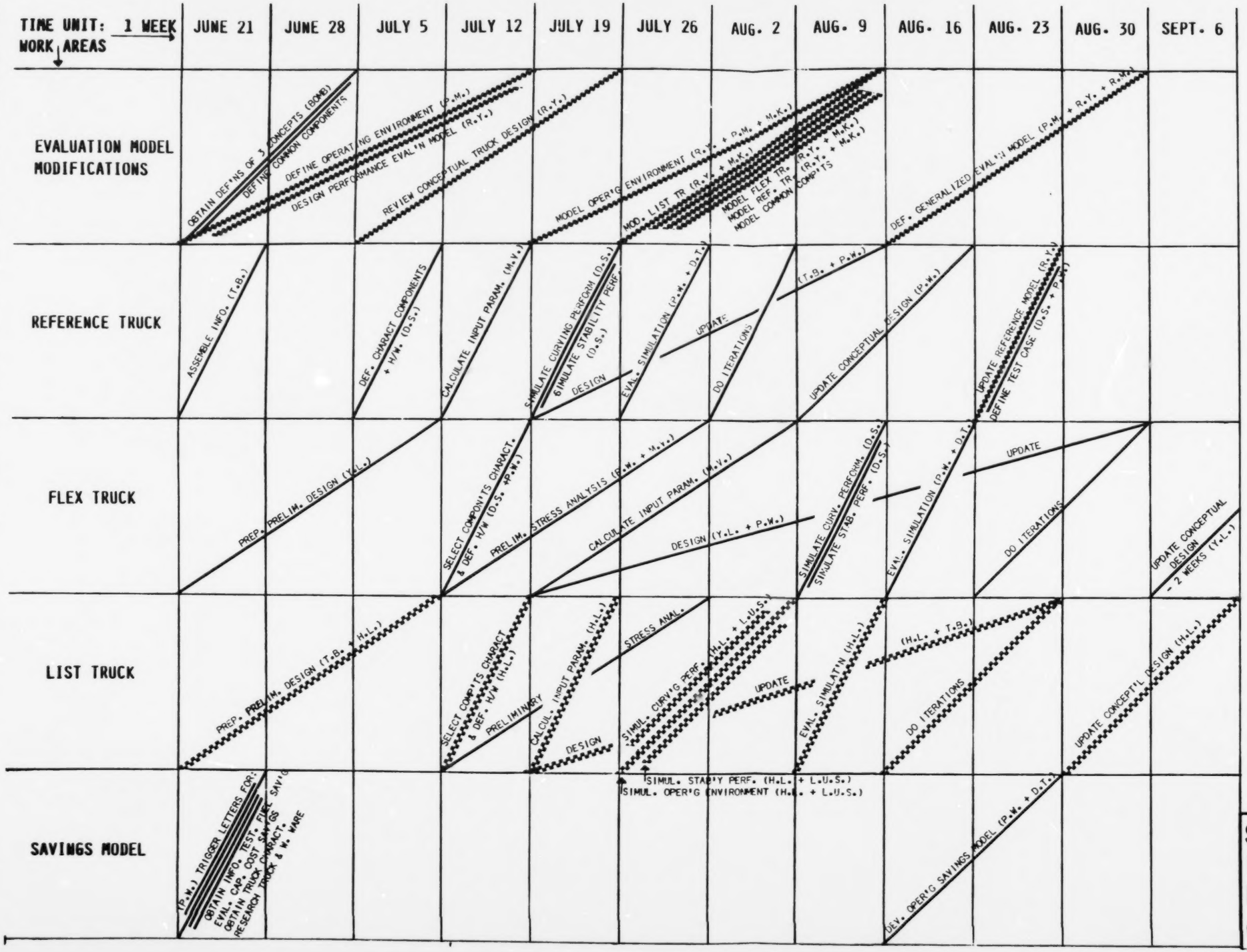
SEPT 82		OCT 82		NOV 82	
PROJ WEEK	CALENDAR WEEK	PROJ WEEK	CALENDAR WEEK	PROJ WEEK	CALENDAR WEEK
11	29- 4	16	3- 9	20	31- 6
12	5-11	17	10-16	21	7-13
13	12-18	18	17-23	22	14-20
14	19-25	19	24-30	23	21-27
15	26- 2		-		-

DEC 82		JAN 83		FEB 83	
PROJ WEEK	CALENDAR WEEK	PROJ WEEK	CALENDAR WEEK	PROJ WEEK	CALENDAR WEEK
24	28- 4	29	2- 8	33	30- 5
25	5-11	30	9-15	34	6-12
26	12-18	31	16-22	35	13-19
27	19-25	32	23-29	36	20-26
28	26- 1		-		-

TWO AXLE LOCOMOTIVE STEERABLE TRUCK - PHASE II 7119

MAR 83		APR 83		MAY 83	
PROJ WEEK	CALENDAR WEEK	PROJ WEEK	CALENDAR WEEK	PROJ WEEK	CALENDAR WEEK
37	27- 5	42	3- 9	46	1- 7
38	6-12	43	10-16	47	8-14
39	13-19	44	17-23	48	15-21
40	20-26	45	24-30	49	22-28
41	27- 2		-		-

JUNE 83		JULY 83		AUG 83	
PROJ WEEK	CALENDAR WEEK	PROJ WEEK	CALENDAR WEEK	PROJ WEEK	CALENDAR WEEK
50	29- 4	55	3- 9	59	31- 6
51	5-11	56	10-16	60	7-13
52	12-18	57	17-23	61	14-20
53	19-25	58	24-30	62	21-27
54	26- 2		-	63	28- 3



LEGEND

BOMBARDIER
DSL
REA

DSL

M.K. - Mike Kelly
G.L. - Gaston Levesque
P.M. - Pierre Marcotte
R.M. - Rod Mathewson
R.Y. - Bob Young

BOMBARDIER

T.B. - Ted Bogacky
Y.L. - Yves Leveillé
D.S. - Deep Satsangi
D.T. - Dave Taylor
M.V. - Mil Vass
P.W. - Peter Whitby

REA

H.L. - Harold List
L.U.S. - Lehigh University students

PARTICIPANTS

Maurice Audette
Harold List
Pierre Marcotte
Dave Taylor
Peter Whitby
Bob Young

SPEC

BY: JPG/DR/kl | DATE: 25/06/82

VELOCITY DIAGRAM FOR:
TWO AXLE LOCOMOTIVE STEERABLE TRUCK DEVELOPMENT PROGRAM - PHASE II
BOMBARDIER/TDC

DOC. # 82-7119-V04

RAC MATRIX

(Responsibility, Authority, Communications)

	PREPARE MONTHLY REPORTS	DEFINE EVALUATION MODEL	DEVELOP & VALIDATE EVALUATION MODEL	VALIDATING VEHICLE MODEL	GENERATING DATA FOR DESIGN SELECTION	SELECTION PROCESS	REFERENCE TRUCK DESIGN	FLEX TRUCK DESIGN	LIST TRUCK DESIGN	DEFINE COST EVALUATION CRITERIA	REPORT WRITING	MONITOR PROGRESS & UPDATE SCHEDULE
TDC											■	
TDC PROJECT OFFICER	▽	△	△	▽	△	▽	△	△	△	▲	□	▽
BOMBARDIER	◐	■	▽	▼○	○	■◐	●	●	○	●	●	○
DSL	○	●	●	●	●	○	○	○	○	▲	○	○
REA	○	▲	▽	▼○	○	▲			●	▲	○	○
DSS											▼	
P.W.												●

PARTICIPANTS

Maurice Audette
Harold List
Pierre Marcotte
Dave Taylor
Peter Whitby
Bob Young

24/06/82	JPG/DR/kl
DATE	BY

LEGEND:

RESPONSIBILITY ○

- Prime Performance ●
- Limited Performance ○
- Coordination ◐

AUTHORITY □

- Must Approve; Executive ■
- Must Recommend For Approval □
- Must Approve; Professional ▼

COMMUNICATION △

- Must Be Consulted ▲ } Discussion
- Must Be Informed △ }
- Must Advise or Guide ▼ } Written
- Must Be Advised ▽ }

SPEC

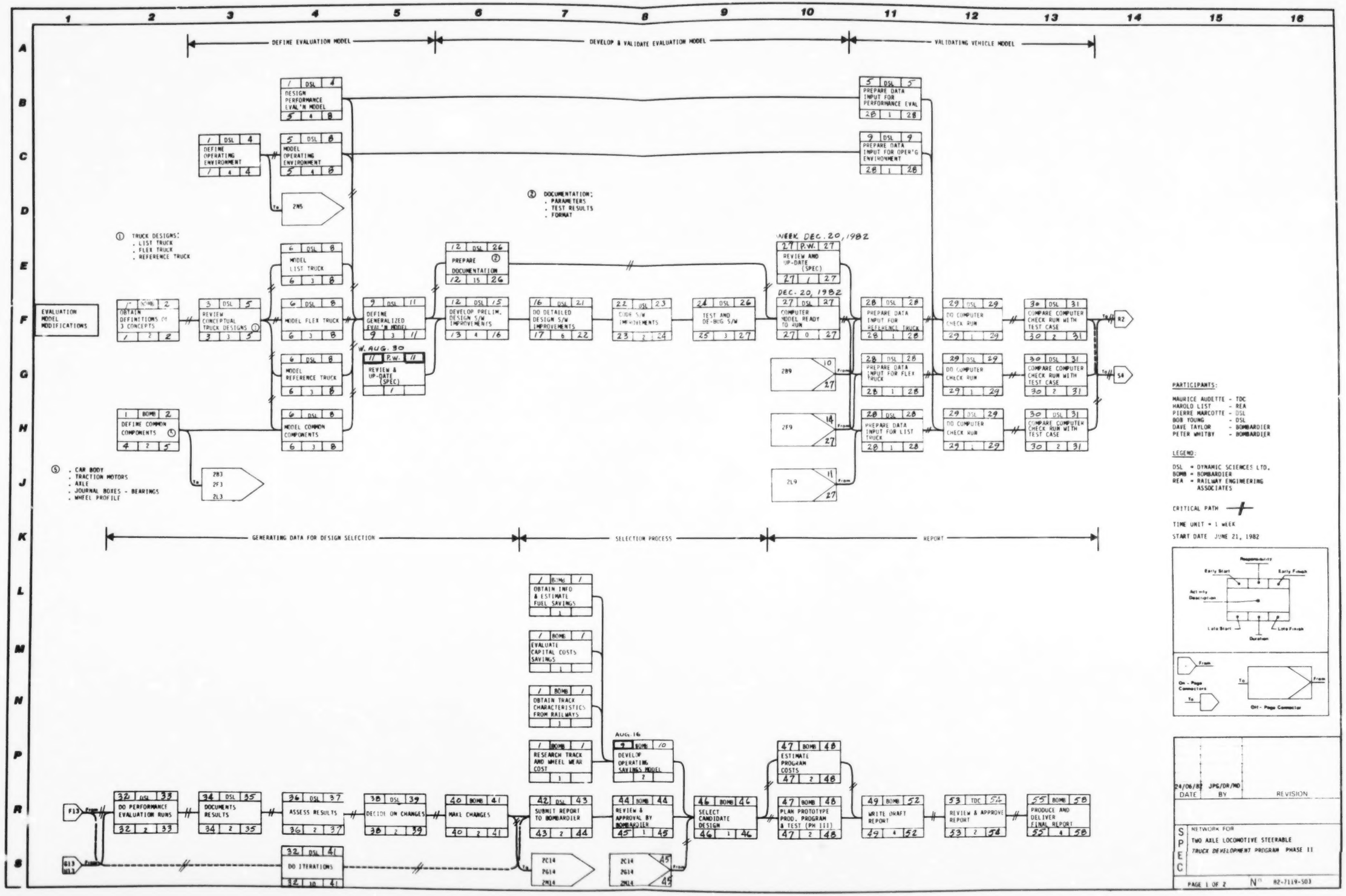
RAC MATRIX FOR:

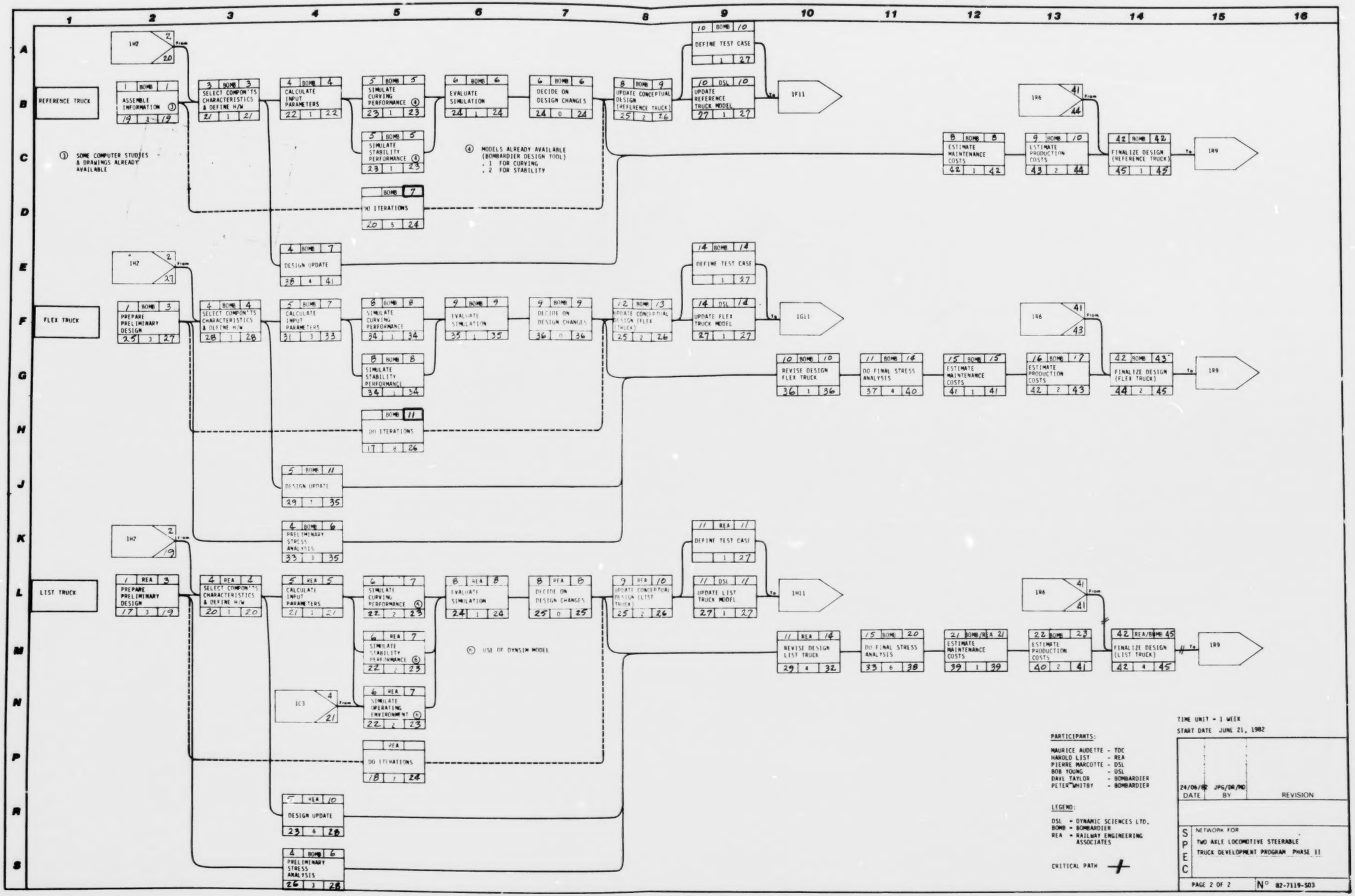
TWO AXLE LOCOMOTIVE STEERABLE TRUCK
DEVELOPMENT PROGRAM - PHASE II

BOMBARDIER/TDC

NO. 82-7119-M01

SYSTEMS SERVICES


DEFINE EVALUATION MODEL
DEVELOP & VALIDATE EVALUATION MODEL
VALIDATING VEHICLE MODEL
EVALUATION MODEL MODIFICATIONS
OBTAIN DEFINITIONS OF 3 CONCEPTS
REVIEW CONCEPTUAL TRUCK DESIGNS
① TRUCK DESIGNS:
. LIST TRUCK
. FLEX TRUCK
. REFERENCE TRUCK
DESIGN PERFORMANCE EVAL'N MODEL
DEFINE OPERATING ENVIRONMENT
MODEL OPERATING ENVIRONMENT
MODEL LIST TRUCK
MODEL FLEX TRUCK
MODEL REFERENCE TRUCK
DEFINE COMMON COMPONENTS ⑤
MODEL COMMON COMPONENTS
⑤ . CAR BODY
. TRACTION MOTORS
. AXLE
. JOURNAL BOXES - BEARINGS
. WHEEL PROFILE
DEFINE GENERALIZED EVAL'N MODEL
W. AUG. 30
REVIEW & UP-DATE (SPEC)
PREPARE ② DOCUMENTATION
② DOCUMENTATION:
. PARAMETERS
. TEST RESULTS
. FORMAT
DEVELOP PRELIM. DESIGN S/W IMPROVEMENTS
DO DETAILED DESIGN S/W IMPROVEMENTS
CODE S/W IMPROVEMENTS
TEST AND DE-BUG S/W
WEEK DEC. 20, 1982
REVIEW AND UP-DATE (SPEC)
DEC. 20, 1982
COMPUTER MODEL READY TO RUN
PREPARE DATA INPUT FOR PERFORMANCE EVAL
PREPARE DATA INPUT FOR OPER'G ENVIRONMENT
PREPARE DATA INPUT FOR REFERENCE TRUCK
PREPARE DATA INPUT FOR FLEX TRUCK
PREPARE DATA INPUT FOR LIST TRUCK
DO COMPUTER CHECK RUN
COMPARE COMPUTER CHECK RUN WITH TEST CASE
GENERATING DATA FOR DESIGN SELECTION
SELECTION PROCESS
REPORT
DO PERFORMANCE EVALUATION RUNS
DOCUMENTS RESULTS
ASSESS RESULTS
DECIDE ON CHANGES
MAKE CHANGES
DO ITERATIONS
SUBMIT REPORT TO BOMBARDIER
OBTAIN INFO & ESTIMATE FUEL SAVINGS
EVALUATE CAPITAL COSTS SAVINGS
OBTAIN TRACK CHARACTERISTICS FROM RAILWAYS
RESEARCH TRACK AND WHEEL WEAR COST
AUG. 16
DEVELOP OPERATING SAVINGS MODEL
REVIEW & APPROVAL BY BOMBARDIER
SELECT CANDIDATE DESIGN
ESTIMATE PROGRAM COSTS
PLAN PROTOTYPE PROD. PROGRAM & TEST (PH III)
WRITE DRAFT REPORT
REVIEW & APPROVE REPORT
PRODUCE AND DELIVER FINAL REPORT
PARTICIPANTS:
MAURICE AUDETTE - TDC
HAROLD LIST - REA
PIERRE MARCOTTE - DSL
BOB YOUNG - DSL
DAVE TAYLOR - BOMBARDIER
PETER WHITBY - BOMBARDIER
LEGEND:
DSL = DYNAMIC SCIENCES LTD.
BOMB = BOMBARDIER
REA = RAILWAY ENGINEERING ASSOCIATES
CRITICAL PATH
TIME UNIT = 1 WEEK
START DATE JUNE 21, 1982
Responsibility
Early Start
Early Finish
Activity Description
Late Start
Late Finish
Duration
On - Page Connectors
Off - Page Connector
24/06/82 JPG/DR/MD
DATE BY REVISION
SPEC
NETWORK FOR
TWO AXLE LOCOMOTIVE STEERABLE TRUCK DEVELOPMENT PROGRAM PHASE II
PAGE 1 OF 2
N° 82-7119-503


REFERENCE TRUCK
ASSEMBLE INFORMATION ③
SELECT COMPONTS CHARACTERISTICS & DEFINE H/W
CALCULATE INPUT PARAMETERS
SIMULATE CURVING PERFORMANCE ④
SIMULATE STABILITY PERFORMANCE ④
EVALUATE SIMULATION
DECIDE ON DESIGN CHANGES
DO ITERATIONS
UPDATE CONCEPTUAL DESIGN (REFERENCE TRUCK)
DEFINE TEST CASE
UPDATE REFERENCE TRUCK MODEL
1F11
DESIGN UPDATE
ESTIMATE MAINTENANCE COSTS
ESTIMATE PRODUCTION COSTS
FINALIZE DESIGN (REFERENCE TRUCK)
1R9
③ SOME COMPUTER STUDIES & DRAWINGS ALREADY AVAILABLE
④ MODELS ALREADY AVAILABLE (BOMBARDIER DESIGN TOOL)
. 1 FOR CURVING
. 2 FOR STABILITY
FLEX TRUCK
PREPARE PRELIMINARY DESIGN
SELECT COMPONTS CHARACTERISTICS & DEFINE H/W
CALCULATE INPUT PARAMETERS
SIMULATE CURVING PERFORMANCE
SIMULATE STABILITY PERFORMANCE
EVALUATE SIMULATION
DECIDE ON DESIGN CHANGES
DO ITERATIONS
UPDATE CONCEPTUAL DESIGN (FLEX TRUCK)
DEFINE TEST CASE
UPDATE FLEX TRUCK MODEL
1G11
REVISE DESIGN FLEX TRUCK
DO FINAL STRESS ANALYSIS
ESTIMATE MAINTENANCE COSTS
ESTIMATE PRODUCTION COSTS
FINALIZE DESIGN (FLEX TRUCK)
1R9
DESIGN UPDATE
PRELIMINARY STRESS ANALYSIS
LIST TRUCK
PREPARE PRELIMINARY DESIGN
SELECT COMPONTS CHARACTERISTICS & DEFINE H/W
CALCULATE INPUT PARAMETERS
SIMULATE CURVING PERFORMANCE ⑥
SIMULATE STABILITY PERFORMANCE ⑥
SIMULATE OPERATING ENVIRONMENT ⑥
EVALUATE SIMULATION
DECIDE ON DESIGN CHANGES
DO ITERATIONS
UPDATE CONCEPTUAL DESIGN (LIST TRUCK)
DEFINE TEST CASE
UPDATE LIST TRUCK MODEL
1H11
REVISE DESIGN LIST TRUCK
DO FINAL STRESS ANALYSIS
ESTIMATE MAINTENANCE COSTS
ESTIMATE PRODUCTION COSTS
FINALIZE DESIGN (LIST TRUCK)
1R9
⑥ USE OF DYNSIM MODEL
PARTICIPANTS:
MAURICE AUDETTE - TDC
HAROLD LIST - REA
PIERRE MARCOTTE - DSL
BOB YOUNG - DSL
DAVE TAYLOR - BOMBARDIER
PETER WHITBY - BOMBARDIER
LEGEND:
DSL = DYNAMIC SCIENCES LTD.
BOMB = BOMBARDIER
REA = RAILWAY ENGINEERING ASSOCIATES
CRITICAL PATH
TIME UNIT = 1 WEEK
START DATE JUNE 21, 1982
24/06/82 JPG/DR/MD
DATE BY REVISION
SPEC
NETWORK FOR
TWO AXLE LOCOMOTIVE STEERABLE TRUCK DEVELOPMENT PROGRAM PHASE II
PAGE 2 OF 2
N° 82-7119-503